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# The chemical control of pests

Man, like the rest of living creation, is engaged in a never-ending struggle for the necessities of life. There is competition from all directions. Many kinds of bacteria, for instance, while individually insignificant, can kill him by sheer weight of numbers. The crops upon which he depends for sustenance are open to attack by hosts of competing organisms; they may be destroyed by disease or smothered by the rank growth of weeds. Countless varieties of insects are inimical to human life and welfare. Some, like locusts and termites, devour foodstuffs or damage property; others, such as mosquitos and lice, are dangerous as disease-carriers. Rats and mice and other vermin take serious toll in similar ways, and the age-old problem of the control of pests is still but partially solved.

The advance of chemistry has given new power to one of the oldest weapons in man's armament of self-protection, namely the use of poisons. The elaboration and application of poisonous substances dates from the earliest times. Those known to the ancients were primarily of natural origin, and included compounds of lead and arsenic, snake venoms, and extracts of certain plants, such as hemlock. We know, too, from the Homeric writings, that the Greeks used sulphur dioxide as a fumigant.

This list comprises many powerful poisons, but their practical use was, and is, limited inasmuch as their action is indiscriminate. They are as deadly to man as to his intended victims—sometimes more so—and their application is therefore attended by considerable difficulty and danger. A great stride forward was taken in the nineteenth century, with the discovery of poisons that are specific in their action. Ehrlich, the pioneer in this work, was able to show that certain arsenical compounds will destroy bacteria in the human body without at the same time doing irreparable damage to the tissues of the patient. There have been few more momentous discoveries, though, as has often happened in similar cases, subsequent progress was not at first rapid. Thousands of further poisons, including dyes, were investigated, but for many years the only other outstanding achievement to note was the discovery of a compound possessing specific action against the trypanosomes of malaria. Within the last decade, however, the chemical control of bacterial pests has been astonishingly strengthened, first by the discovery of the sulphonamide drugs—efficient specifics against staphylococci and streptococci—and more recently by the discovery of penicillin, a substance so highly specific against certain bacteria that the risk of giving a patient an overdose is negligible.

These discoveries were important not only because of their immediate application, but because they proved beyond the possibility of doubt that the search for specific poisons offered every prospect of reward. They thus opened up a new field of chemical activity—a field that is already bearing fruitful crops. We publish in the present issue an article by Dr R. E. Slade, in which some recent work on the subject is described. A feature of much interest is that specific poisons have now been found for certain plants, and have already been applied in agriculture for the destruction of weeds. The original observation was that a number of growth-promoting compounds, chemically allied to α-naphthyl-acetic acid, have a powerful effect in the contrary sense when applied at greater concentrations. One of these substances, 'methoxone,' has now been developed commercially, and has proved of very considerable value in freeing cereal crops—which are almost unaffected by it—from harmful weeds such as charlock.

The pyrethrums and derris are examples of

natural poisons with a specific action against insects. To them have been added during the past few years the synthetic substances 'D.D.T.' (dichlorodiphenyl-trichloroethane) and 'gammexane, the γ-isomer of benzene hexachloride. These substances, although not very toxic to animals and almost without effect upon the leaves of plants, are among the most powerful insecticides known.

The majority of the specific poisons hitherto investigated were discovered either by chance or by the laborious examination of thousands of different compounds in the hope that, sooner or later, useful ones would be found among them. An urgent need for the speedy development of this important branch of applied chemistry is a more logical method of search; and as this can come only from an understanding of the mechanism of specific toxicity it is satisfactory to know that a beginning has been made in this direction. There is indeed evidence that at least some specific poisons act in virtue of their chemical resemblance to substances which play essential parts in metabolism. One such substance is *p*-aminobenzoic acid, to which the sulphonamides have a general similarity of structure; and Fildes and Woods have suggested that the toxic action of the sulphonamides may be explained on the assumption that their molecular architecture enables them, so to speak, to act as faulty keys that enter, but jam, locks properly turned by *p*-aminobenzoic acid. By replacing this acid in a cell reaction, they distort or stop the normal course of the metabolism. Similarly, it has been suggested that the toxic action of gammexane is attributable to its structural resemblance to the natural form of inositol. These hypotheses are still highly speculative, but they form a point of attack and may lead to a gradually increasing comprehension of the mode—or modes—of action of specific toxicity.

Whether progress be rapid or slow, the discovery of specific poisons makes it clear that we approach an age in which the destruction or control of pests by chemical means will become more and more practicable. At first sight, the prospect would appear wholly delectable: fields and gardens without weeds, granaries and warehouses without rodents, each bacterial disease with its appropriate chemical antidote. Caution, however, bids us pay attention to the fact that dangers may lie ahead. Man occupies a place in a complex system of interacting organisms, among which a state approximating to dynamic equilibrium exists. He now possesses the means of radically altering several of the factors in this system, and is naturally tempted to employ them at once to what he believes will be his advantage. Yet while the immediate effects of such control may be favourable, human foresight is still too limited for us to be certain that the ultimate effects will continue to be favourable. On the contrary, it is easily conceivable that destruction of one pest may promote the increase of another upon which it normally preys; for, as Augustus de Morgan wrote:

> 'Great fleas have little fleas upon their backs to bite 'em,
> And little fleas have lesser fleas, and so *ad infinitum*.'

Interference with the balance of nature must be attended by more or less risk, and it does not require a very vivid imagination to picture the consequences of, say, the destruction of the nitrifying bacteria of the soil. Such a complete disaster may be unlikely, but minor ones of the same kind could be sufficiently disturbing, and their possibility could not be ruled out if chemical control of pests were applied without due discretion and preliminary investigation.

These general conclusions are of course obvious upon reflection; unfortunately there is little evidence that they are receiving serious study. It seems not improbable that future use of selective poisons may do more to change the face of living nature than any previous application of scientific knowledge; it would be a tragedy if, through premature or ill-considered action, discoveries which have immense power for good should be so mishandled as to occasion misfortune and evil.

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Contributions and correspondence should be sent to the editor: E. J. Holmyard, M.A., M.Sc., D.Litt., F.R.I.C., Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1. Scientists engaged in research of an interesting or important character are invited to send short notes on work in progress and results obtained.

# The measurement of time

SIR HAROLD SPENCER JONES

Recent advances in physics, particularly in the field of electronics, demand very high precision in the measurement of time. In this article the Astronomer Royal shows how this demand has been met by the development of new astronomical methods for providing standards of time, and by the construction of ingenious new types of clock capable of recording the passage of time with an error not exceeding one-tenth of a millisecond daily.

Of the three fundamental dimensional quantities of physics—mass, length, and time—there is an essential difference between time and the other two quantities. Permanent material standards of mass and length are possible, with which other masses and lengths can be compared. But no standard of time that is permanent, in the sense of being invariable, is available. Any phenomenon that repeats itself with absolute regularity could serve, if provided with a suitable counting mechanism, as a permanent standard of time, and would form a perfect clock.

The perfect clock, however, is a theoretical ideal, which is not practically attainable. Whatever clock is used for the measurement of time must therefore be checked at frequent intervals, if precision in absolute time or in time intervals is required. This is a complicating factor which is peculiar to time; the physicist does not need to check his standards of mass and length from day to day to see whether, or by how much, they have varied.

But what is to serve as the check on our clocks, and thereby, in effect, to provide our basic standard of time? The rotation of the Earth on its axis provides us with our fundamental unit of time, the day. We assume that this unit is invariable, though we shall see later that this assumption is not strictly correct. Now the day can be defined in various ways. We can choose some convenient reference point—which may be the Sun or a star or some fictitious point or body—and define the day as the interval between two successive transits of that point over the same meridian. The length of the day will depend upon the particular choice of the reference point; if the reference point has a motion that is not uniform, the day will vary in length.

When the Sun is chosen as the reference point, the day which it defines is called the apparent or true solar day. The apparent solar day is not uniform in length, because the rate of the Sun's apparent diurnal motion around the axis of the Earth is not uniform. This arises partly from the variation in the distance of the Earth from the Sun and partly from the fact that the axis of the Earth's rotation is not perpendicular to the Earth's orbit. The variations in length are considerable; in the latter part of December, for instance, the apparent solar day is about 50 seconds shorter than in the middle of September. A clock of very moderate quality will keep better time than this. The apparent solar day is therefore not suitable for the purposes of everyday life. A fictitious mean Sun is accordingly imagined to move uniformly in the equator, with a motion equal to the mean motion of the true Sun. The mean solar day is the interval between successive transits of this mean Sun across the same meridian; it is the common day of civil life. The time determined by the mean Sun is known as mean solar time or simply as mean time.

But, in practice, time must be determined from observations of the stars. The time of transit of the Sun, because of its size and brightness, cannot be determined with the accuracy with which the time of a star transit can be determined. There are, moreover, many stars but only one Sun. The interval between two successive transits of a star without proper motion is called the sidereal day, and is the true period of the Earth's axial rotation. It is about four minutes shorter than the mean solar day, because the Earth in the course of one rotation has moved approximately one degree relative to the Sun along its orbit; thus the Earth has to turn through approximately 361 degrees between two successive transits of the mean Sun.

Actually, however, the sidereal day is defined by successive transits not of a star but of the vernal equinox, the point in the heavens where the ecliptic crosses the equator from south to north. It is necessary to define the sidereal day in this

way in order to permit of the conversion of sidereal time into mean time. But the equinox has an annual retrograde motion along the ecliptic of about 50 seconds, resulting from the precessional motion of the Earth's axis. The sidereal day, as defined, is thus 0·009 seconds shorter than the true period of the Earth's rotation and is actually equivalent to 23 hours 56 minutes 4·091 seconds of mean solar time. A clock giving sidereal time will indicate nought hours at the moment of each transit of the vernal equinox, so that the interval between two successive transits is exactly 24 hours in sidereal time.

Mean time is derived from sidereal time in the following way. The interval, measured in sidereal time, between the transit of the vernal equinox and the transit of a body is termed the right ascension of that body; it is one of the co-ordinates used in defining the position of the body in the sky, the other being its declination, or angular distance north or south of the equator. It follows that, since the vernal equinox transits at nought hours sidereal time, the sidereal time at which the body transits is equal to its right ascension. But the mean Sun transits at mean noon; hence the sidereal time at mean noon is equal to the right ascension of the mean Sun, which can be calculated and is given in the *Nautical Almanac* for every midnight. Thus when sidereal time has been determined, the instant of mean noon can be found; in other words, the conversion from sidereal time to mean time becomes possible.

But there is a complication. The motion of the vernal equinox is not uniform, because superimposed upon the conical or precessional motion of the Earth's axis is a nodding or nutational motion, arising from perturbations by the Sun and Moon. The conception has therefore to be introduced of a *mean equinox*, whose motion is uniform and equal to the mean motion of the true equinox. Just as it is necessary to distinguish between apparent or true solar time and mean solar time, so also it is necessary to distinguish between apparent or true sidereal time and mean sidereal time. The difference between apparent and mean sidereal time is never large; the distinction has, in fact, been made only within the last 20 years or so. The difference between apparent and mean sidereal time may amount to about $\pm$ 1·2 seconds. The major portion of this difference, amounting to $\pm$ 1·06 seconds, has a period of 18 years, the period of revolution of the nodes of the Moon's orbit. It is, however, the short period components which are of greater importance in precision time measurement, though they are smaller in magnitude. The principal terms are a six-monthly term, amounting to $\pm$ 0·080 seconds, and a term with a period of half a lunar month, or about 15 days, which, in combination with other and smaller terms, may amount to $\pm$ 0·020 seconds. The precision of modern clocks has made it necessary for these small terms to be taken into account. The *Nautical Almanac* tabulates, for nought hours each day, the apparent sidereal time and the difference between apparent and mean sidereal time, called the nutation in right ascension.

We have seen that the sidereal time at the instant of meridian transit of a star is equal to the right ascension of the star. If then we determine the instant of meridian transit of a star whose right ascension is known, the sidereal time becomes known. This is the basis of the determination of time. In actual practice the measurement of time reduces to finding the error and rate (or change of the error in 24 hours) of the sidereal standard clock. By finding the time by the clock at which a star of known right ascension transits, we obtain the clock time corresponding to a definite instant of sidereal time. Thus the error of the clock is determined. By repeating the observation the following night the change in clock-error in 24 hours, which is the rate of the clock, is also determined. To reduce the effect of errors of observation each determination of the clock error is based on the observation of some 16 or 20 stars.

The observations for the determination of time are usually made with a transit instrument—a telescope supported from a horizontal east-west axis, enabling it to be moved in the plane of the meridian. When the instrument is set on a star just before the time of its meridian transit, the star is seen moving across the field of view, the speed of its motion depending upon its distance from the pole. To determine the instant of meridian passage, some form of chronograph is needed. In the older method of observation, a number of vertical spider-webs, generally called 'wires,' are fixed in the focal plane of the object-glass. As the star crosses each wire, the observer depresses a tapper, mounted on the telescope in a convenient place near the eyepiece, which closes an electric circuit and causes a signal to be sent to the chronograph. The standard clock also sends signals to the chronograph. The clock signals and transit signals are both recorded on a moving drum or tape, and the clock times of each transit signal can be

read off subsequently. The positions and spacings of the wires having been determined, the time of meridian transit can be inferred from the time of transit across each wire; the mean is adopted as the observed time of transit.

Such observations are liable to a considerable 'personal equation.' One observer will make his tap when he sees the star actually bisected by the wire; another will anticipate and shoot the flying bird, as it were. Systematic personal differences of as much as half a second can occur between two competent and reliable observers. The so-called impersonal micrometer is therefore now almost invariably used in time determinations. Instead of a number of fixed wires, there is a single wire, fixed to a movable frame. The observer traverses this frame along, by means of a milled head at each end of the traversing screw, so that the star image remains bisected by the wire; a contact wheel, mounted on the screw, sends signals to the chronograph, enabling the time of transit to be determined. With this form of micrometer the personal equations of different observers never exceed more than two or three hundredths of a second. A further refinement, to relieve the strain on the observer involved in traversing the wire uniformly and maintaining an accurate bisection of the star image, is to drive the wire mechanically at a speed appropriate to the distance of the star from the pole, the observer being merely required to maintain accurate bisection by means of a differential gear.

These small residual personal equations can be determined with a personal equation machine. The principle is to observe transits of an artificial star, whose position is recorded on the chronograph along with the observed positions.

A number of corrections have to be applied to the observations, the most important being the errors of level, azimuth, and collimation, and of the figure of the pivots. These errors, except the last, are liable to annual and diurnal changes and must be carefully controlled. In the determination of time, it is usual to employ a small reversible instrument; near the time of meridian passage of a star, when half the transit has been observed, the telescope is reversed in its bearings, the second half of the transit being observed in the reversed position. By this means the collimation correction is eliminated; but it is then impracticable to determine the level error by a nadir observation with a mercury horizon, because this requires the collimation to be known. A striding level, embodying a very sensitive bubble, is therefore used; but this has its own disadvantages and the difficulty of accurately determining the level error and its variations provides one of the principal limitations to the precision of the observations. The probable error of a single determination of time, based on the observation of about 16 stars with a small reversible transit instrument, is at least $\pm$ 0·010 seconds. For the provision of a time service of high precision, an appreciable reduction in the probable error of the time determinations is desirable.

At the Naval Observatory, Washington, such a reduction has been obtained by an ingenious application of a photographic zenith telescope, designed originally by Dr F. E. Ross for the determination of the variation of latitude. The principle of the instrument is that of the reflex zenith tube, designed by Airy and used at the Royal Observatory, Greenwich, for many years for determining the variation of latitude. The telescope is fixed in position, pointing towards the zenith. The converging rays of light from the objective are reflected back by a mercury horizon, whose position is so adjusted that the focal plane passes through the second principal Gaussian point of the objective. When this condition is accurately satisfied, the positions of the star images are independent of the level error and of its variations. In the Airy instrument the observations were visual; the Gaussian point was just above the objective, and the converging light, when near its focus, had to pass through the objective a second time. This impaired the accuracy of the observations. In the Ross instrument, the Gaussian point was brought below the objective by placing the flint component uppermost. By separation of the two components, the distance of the Gaussian point from the objective was increased sufficiently to enable a photographic plate to be placed in the principal focal plane. Round images of the stars are obtained by giving exposures of suitable length and traversing the plate at the appropriate speed. The objective together with the plate can be rotated through 180 degrees. By giving two exposures on a star, at approximately equal times before and after its meridian transit, the objective being rotated through 180 degrees between the two exposures, the time of meridian transit can be inferred. Suppose that $T_0$, $T_1$, $T_2$ denote the required time of meridian passage and the mid times of the two exposures respectively, and that $x_1$, $x_2$ denote the distances (in millimetres) of the two images on the plate from the meridian plane. If $s$ denotes

the scale of the plate, expressed in seconds of time per millimetre, it follows that

$$T_1 + x_1 s = T_0 = T_2 - x_2 s,$$

giving $$2T_0 = T_1 + T_2 + s(x_1 - x_2).$$

The separation of the two images in the right ascension direction $(x_1 - x_2)$ can be measured in a micrometer, and $T_1$ and $T_2$ are chronographically recorded against signals from the standard clock, so that the clock time of meridian passage of the star is determined. Knowing the right ascension of the star, the clock error is deduced.

This method of time determination has many advantages. The telescope is fixed in position, instead of being pointed in a different direction for each star to be observed; the observations are made in the zenith, where conditions are most favourable; the use of photography gets rid of troublesome personal equations; the effects of level error are eliminated and those of other errors are reduced to a minimum. The probable error of the time determined from the observation of a single star does not exceed $\pm$ 0·010 seconds, and the mean of a night's observations gives the time with a probable error of only two or three milliseconds.

A photographic zenith telescope of improved design is being constructed for the Royal Observatory, Greenwich. This telescope will have an object glass of 10 inches aperture, which will permit of an ample selection of stars for observation. The plate will be driven, during the exposures on the stars, at a uniform rate controlled by the 1,000 cycles per second output of one of the quartz crystal clocks described below.

Whatever method is used for the determination of time, the right ascensions of the stars observed must be known. The determination of an accurate system of right ascensions extending round the sky is a long and intricate business. The results from a large number of different instruments are coordinated and combined into what is termed a fundamental catalogue. The positions in this fundamental catalogue are used for the determination of time with transit instruments. This has the additional advantage that the times determined at various observatories can be directly compared, as they are free from errors that would be introduced by the use of different systems of star places. With the photographic zenith telescope, observations are limited to a narrow belt of sky at the zenith; faint stars, which are not contained in the fundamental catalogue, must therefore be observed. Special observations with a transit instrument are consequently necessary to relate the positions of these stars to the fundamental system. The positions so derived are smoothed out by the results of the observations with the zenith telescope.

The apparent position of a star is affected by aberration, precession, nutation, stellar parallax (which can be neglected except for the nearer stars), and the proper motion of the star. For the stars in the fundamental catalogue, the apparent places at 10-day intervals are published annually by the Nautical Almanac Office of the Royal Observatory, based on computations made at the ephemeris offices of the United States, France, Germany, and Spain. For time determinations, the apparent place must be interpolated to the time of observation. Apparent places of the faint stars observed with the photographic zenith telescope are not available, and must be specially computed.

A determination of time gives the error of the clock, with which the observations are compared, at a certain instant. But the time determination is itself subject to error. When the error of the clock has been determined on a number of nights, a smooth curve can be drawn to fit these as closely as possible, and the clock error can then be interpolated for any intermediate time. This procedure assumes that it is legitimate to suppose that the clock-error varies in a regular way. But in order to make time available to the public by the distribution of time signals, it is necessary to predict the clock error at some future instant, which is a process of extrapolation. Several days may easily elapse without any time determinations being possible; if the rate of the clock is erratic, the extrapolated clock-errors may prove to be appreciably wrong. Hence it is important that any observatory concerned with the determination and distribution of time should be equipped with the most accurate clocks available.

The pendulum clocks of the highest precision are those of the Shortt-Synchronome free-pendulum type. These clocks achieve in a beautifully simple manner what horologists had been aiming at for many years—to put on to an auxiliary slave clock all the work involved in driving a train of wheels in order to record the time on a dial, and in sending out signals; this clock to be controlled by a master clock, whose pendulum is allowed to swing freely and without disturbance, except for the periodic impulses needed to keep it swinging. In the Shortt-Synchronome free-pendulum clock, the slave clock is rated so that, when running as an independent clock, it loses

about 6 seconds a day. The process of synchronization by the master-pendulum is then a one-way action, the slave clock being accelerated as necessary. The essential part of the synchronization mechanism is the 'hit and miss' synchronizer; the armature of a small electromagnet, operated each half-minute by a current from the master clock, can engage with the lip of a spring, mounted on the slave pendulum. When such an engagement occurs, the spring is flexed as the pendulum swings, and the pendulum is thereby accelerated by 1/240th second; but the engagement will not occur unless the slave pendulum is sufficiently late on the free pendulum. The natural rate of loss of the slave pendulum being 6 seconds a day, or 1/480th second in half a minute, and the synchronizing current passing each half-minute, it follows that when functioning normally the synchronizer will hit and miss alternately; hence its name.

Clocks of this type were installed at the Greenwich Observatory in 1924. The free pendulum is mounted in an air-tight case in a chamber maintained at a constant temperature, so as to be free from the effects of varying atmospheric pressure and varying temperature. The pressure in the case is lowered to about one inch of mercury, to reduce the effects of air resistance. It has been found that their timekeeping is accurate to the order of one or two hundredths of a second a day. The experience with these clocks at Greenwich showed that the variations in rate were partly attributable to the neglect to take into account the short period terms in the nutation, and it became necessary to make the distinction between apparent and mean sidereal time. The much larger variations in rate of the regulator clocks, previously used as standard clocks, had not required this distinction to be made.

Further experience showed that these clocks, good as they are, still leave something to be desired. Their rates are liable to small erratic variations which, by integration, give rise to an irregular wandering of the clock from true time. There is no means of discriminating between the errors in the time determinations and the erratic variations in the rate of the clock; when the clock errors have been plotted, it is not justifiable to represent them by a smooth curve. The time service is based on the mean of a number of clocks, which reduces the effect of the wandering of any one clock; but as each clock wanders irregularly, it is still impossible to extrapolate with certainty in order to predict the clock error at some future time.

Meanwhile, the development of precision frequency standards, controlled by quartz crystal oscillators, showed that these gave a better standard of performance, when regarded as clocks, than the free pendulum clocks. When the frequency standards were checked against the time signals, apparent fluctuations in frequency were obtained, which were not confirmed by intercomparison between the frequency standards themselves. The unsatisfactory position had been reached of the time signals providing the only available check on the frequency standards, whilst the day to day performance of these standards was of a higher degree of precision than that of the standard clocks at the Observatory. As the Royal Observatory is responsible for the time service of Great Britain, it has an obligation to meet all demands upon the service in the matter of precision in timekeeping. It is in order to meet the demands for very high precision in time signals, necessitated by modern electronic developments, that pendulum clocks are being replaced by quartz crystal clocks as the standards of time at the Royal Observatory.

The quartz crystal clock depends upon the piezo-electric property of quartz. When pressure is applied to the opposite faces of a piece of quartz, electrical charges of opposite sign appear on two faces at right angles. Conversely if the quartz plate is placed between two metal plates which are electrically charged, one positively and the other negatively, the plate expands or contracts in a direction perpendicular to that in which the electrical charges have been applied. If the two metal plates are connected to an alternating current circuit, so that the voltage of the plates is being continuously reversed, the quartz plate will be maintained in a state of vibration. When the frequency of the alternation is close to the natural resonance frequency of the quartz plate, this frequency takes control and the relatively unstable frequency of the alternating circuit is held very steady.

The quartz clocks installed at the Royal Observatory have been designed and constructed in the Radio Branch of the Post Office. The quartz oscillator is in the form of a small rectangular plate, the dimensions of which are adjusted so that the resonance frequency is very close to 100,000 per second. The plate is cut from a natural crystal of quartz, carefully selected to be free from optical and electrical twinning; it is mounted at nodal points of the vibration and is maintained at constant temperature in a thermostatically controlled

oven. The plate is cut in a certain direction relative to the optic axes of the crystal, known as the GT cut, which gives a very small dependence of frequency on temperature. The drive circuit for maintaining the plate in vibration is not a simple valve circuit; for greater accuracy a bridge-balanced circuit is used, which is balanced only when the crystal is oscillating at its natural resonance frequency. It is found that the frequency remains constant to about one part in one hundred million.

These crystal-controlled sources of constant frequency are known as frequency standards, and are used for many purposes, such as controlling the frequencies of radio transmitters. To use them as clocks it is necessary to have some means of counting up the vibrations. One method is to use a valve oscillator circuit known as a 'multivibrator' which, in addition to its fundamental frequency, has a whole series of harmonics. If the fundamental frequency of the multivibrator is approximately 10,000 cycles per second, the frequency of its tenth harmonic will be approximately the same as that of the quartz crystal. By feeding a little of the crystal-controlled frequency into the multivibrator, the frequency of its tenth harmonic is locked into step with the crystal frequency. The fundamental frequency of the multivibrator then becomes exactly one-tenth of that of the crystal. A second multivibrator can be employed to obtain an output of 1,000 cycles per second, exactly one-hundredth of that of the crystal. A better method, which is employed in the Observatory clocks, is to use circuits known as fractional frequency generators. The output from the quartz crystal is fed into one of these generators, which gives an output of exactly half the original frequency. This output is in turn fed into a second generator, which gives an output with frequency of exactly one-fifth of the input and therefore one-tenth of that of the crystal. Two further similar generators are employed for the next stage of frequency division, giving a final output of 1,000 cycles per second. When multivibrators were used it was possible, if the crystal had stopped vibrating for any reason, for the two divider circuits to remain locked together and still give an output, thereby giving a spurious result. This is not possible when fractional frequency generators are used; failure of the crystal circuit then results in complete stoppage.

An output with a frequency of 1,000 cycles per second having been obtained, it can be used to drive a synchronous motor, provided with contacts to give impulses every second and every tenth of a second. The motor may also drive a pair of hands, through suitable gearing, as in the ordinary mains electric clock, and thus indicate hours, minutes, and seconds. Alternatively, the frequency can be still further divided to provide a frequency of ten cycles per second. The sinusoidal oscillations can then be transformed by a suitable trigger circuit to give sharp pulses at intervals of one-tenth of a second.

The quartz clocks being installed at the Royal Observatory are all adjusted to give a frequency of approximately 100,000 per mean time second. By suitable gearing, the synchronous motor can give impulses every sidereal second and tenths of seconds. Thus the same clock can be made to serve both as a mean time and as a sidereal time standard. All time signals are, of course, sent out according to mean time; the sidereal time is required only for the actual time determinations, so that it is not necessary for all the clocks to have the gearing to give sidereal seconds.

It is possible also by a simple gearing to obtain impulses spaced at intervals of 60/61 seconds, and thus for the clock to send out impulses, accurately spaced at 61 to the minute, which form the rhythmic or vernier time signals, used for navigational purposes to enable the error of a chronometer to be accurately determined.

The great superiority of the quartz crystal clocks over the best pendulum clocks lies in the fact that they are free from the small erratic changes of rate to which the pendulum clocks are liable. Changes of rate may occasionally occur, but they are definite, and after a change has occurred the rate again remains steady. Thus the clock errors, as indicated by the time determinations, can be plotted and represented by a straight line, or possibly by a series of straight lines. This enables the uncertainty of prediction of the clock error to be greatly reduced.

The quartz clocks have another great advantage for the maintenance of a time service of high precision. Their relative rates can be readily determined to a very high degree of accuracy. The frequency of the crystal in each case is adjusted to be very close to the nominal frequency of 100,000 per second. By combining the frequencies of two clocks in a suitable electrical circuit, the beat frequency between the two clocks can be obtained. The accuracy of adjustment is such that the beats between two clocks occur at intervals of a minute or so. The beats can be shown on a meter and the time of 10 or 20 beats can be

counted. The difference in the frequencies of the two clocks is equal to the fraction of a beat occurring in a second. From this measured difference in instantaneous frequency, the relative daily rate of the two clocks is at once obtained. In this way, the relative rate can be readily obtained with an accuracy better than one-tenth of a millisecond a day.

It is possible also to employ a magnetic beat counter, which counts up automatically the beats between two clocks. The number of beats in the course of 24 hours can thus be obtained. This, in effect, gives an integration of the relative rate, and thus gives the time difference between the two clocks which develops in the course of a day. Thus the relative daily rate of two standards can easily be obtained with an uncertainty of less than one-hundredth of a millisecond. As these comparisons are based directly on the primary nominal frequency of 100,000 cycles per second, it is not necessary for all the standards to be provided with the dividing circuits and phonic motors to give seconds and tenths of seconds. This means a substantial saving in equipment.

The quartz crystal clocks suffer from one disadvantage compared with pendulum clocks. Pendulum clocks can run for long periods—up to several years—without stopping. But the valve circuits involved in a quartz clock cannot be expected to operate for such lengthy periods without a breakdown. When the clock is restarted, a change of rate is likely to have occurred; but the new rate can be readily and accurately determined by comparison with other clocks, so that any discontinuity in rate can be allowed for. The quartz clocks of the Royal Observatory are arranged in groups of three, each such group forming a unit. The three clocks in each group are regularly intercompared: AB, BC, and CA. If any of the three should stop, comparisons with the other two enable any discontinuity in rate to be determined. The individual groups are similarly intercompared. The stoppage of any one clock is therefore not serious, though it is important that all the clocks should not stop at once. This would happen in the event of a mains failure, if the clocks were mains operated. To guard against this, the oscillators are operated from batteries. The current for the heating and control circuits is obtained from the mains; a short interruption in this supply is immaterial. In the event of a mains failure, an alternator comes automatically into operation in the course of a few seconds and provides the current required for the temperature control. Though pendulum clocks seldom stop, each stoppage is serious, as a pendulum clock usually takes weeks to settle down to a fairly steady rate, after it has been started up.

A further application of the quartz oscillators is to operate a counting unit, which is termed a decimal counter chronometer. The 100,000 cycle per second output from one of the primary standards is fed into a special valve-operated counting unit, which counts, on the scale of ten, the number of complete oscillations occurring between the application of two impulses whose time difference it is desired to measure; the count is shown on five separate dials. As one unit is counted every ten microseconds (i.e. in $10^{-5}$ seconds), the total number counted is the time difference in units of ten microseconds. It can be arranged, for instance, for one clock to switch on the counter and for the second to switch it off; to provide a check, the roles of the two clocks can then be reversed. For additional accuracy, it can be arranged that this operation shall be automatically repeated ten times and then stopped, the total count being recorded. The clock and a radio time signal can be similarly compared. A much higher accuracy can be attained than by the use of the usual type of tape chronograph and, in addition, the answer is given directly, without the tiresome reading of lengths of chronograph tape. When the decimal counter chronograph was first used in this way, it was expected that the comparisons between the clocks and the radio signals would be possible only under conditions of good reception. It was, however, found that the method can be used when background mush is so bad that the tape record is almost indecipherable. The reason is that the counter requires a sharp trigger action to operate it and the background mush does not normally possess the necessary sharpness. Several sets of comparisons are always taken, in order to provide a check.

When the installation at the Royal Observatory of the full projected complement of 18 quartz crystal standard clocks has been completed, and when the photographic zenith tube has been brought into operation, so enabling the probable error of a time determination to be reduced to two or three milliseconds, the time will be determined with an accuracy never hitherto attained. This will open up some interesting possibilities. We have so far assumed that the length of the day, defined by the rotation of the Earth with respect to the mean equinox, is invariable in length.

Astronomical observations have shown that this assumption is not in fact correct. Halley, in 1695, found, by comparing positions of the Moon given by observations in his day with the positions derived from early observations of eclipses, that the mean motion of the Moon was being accelerated. Then, in the latter part of the nineteenth century, Newcomb found that there were fluctuations in the Moon's motion, which could not apparently be accounted for by any known gravitational action. Brown's exhaustive investigations of the theory of the Moon's motion, culminating in his *Tables of the Motion of the Moon*, confirmed Newcomb's result. It has since been conclusively established that the Sun, Mercury, and Venus also show secular accelerations of their mean motions and, in addition, irregular fluctuations, which are similar to those in the Moon's motion, but smaller in amount, in the ratios of their relative mean motions. The similarity of the effects for the Moon, the Sun, Mercury, and Venus shows that it is the Earth which is the culprit and that our standard of time, supposedly constant, is really variable.

The secular accelerations in the mean motions are caused by a slow lengthening of the day; this is adequately accounted for by tidal friction in shallow seas, which acts as a brake on the earth. The increase in the length of the day amounts only to about one-thousandth of a second in the course of a century; so small a change is immaterial in the measurement of time to our new order of accuracy, though cosmically it will eventually be very important, because its effects are cumulative. The day will go on lengthening, until eventually the Earth will always turn the same face to the Moon; the day will then be equal in length to 47 of our present days.

The irregular fluctuations in the apparent motions are caused by changes in the length of the day, which have amounted to as much as five milliseconds, the day sometimes getting longer and sometimes shorter. The cause of these changes is not known with certainty, but slight expansions or contractions in the radius of the Earth amounting to a few inches would be sufficient to account for them: such small changes in radius cannot, of course, be detected by direct observation. The changes appear to occur rather suddenly, but the astronomical observations are not of sufficient accuracy to say whether they occur instantaneously or in the course of a few months, or even of a year or two. With the prospect, now open, of determining the length of the day with an uncertainty not exceeding one-tenth of a millisecond, there should be a good chance of determining how suddenly such changes occur. To have an adequate check, it will be essential for the quartz clocks to be maintained in operation for some years, the discontinuity in rate caused by every stoppage of a clock being accurately controlled.

A new era in time measurement has arrived, and clocks made by man now hold out a distinct promise of being able to convict the Earth of irregularities in timekeeping.

# Atomic energy

The atomic bomb, which proved the decisive factor in ending the war against Japan, represents something far more than a new and terrible weapon of destruction. Immensely valuable though it has proved in avoiding the hundreds of thousands of casualties inevitable if the war in the East had been settled by a long struggle between the opposing armies, the new principles used in its construction, applied to useful ends, are unquestionably destined to alter the whole history of mankind. For the first time it has been possible to convert matter into energy on a scale large enough to be put to practical use and under conditions in which the energy needed to start the reaction is insignificant compared with that obtained from it. The task of science is now to solve the further problem of so regulating the disintegration of atoms that the vast store of energy thus made available can be used efficiently and safely, not for destructive purposes, but in the service of all mankind.

It is a matter for great satisfaction that British scientists have played a major part both in establishing the fundamental principles involved in the liberation of atomic energy and in completing the long and difficult task of turning these principles to practical use. An excellent official summary of the extent of their contribution has now been published as a Government White Paper.[1]

[1] *Statements Relating to the Atomic Bomb*. London: His Majesty's Stationery Office, London, 1945. Price 4d. net.

# History of the Cavendish Laboratory, Cambridge

ALEXANDER WOOD

The 'Cavendish' was one of the first laboratories to be founded exclusively for the study of physics, and the researches carried out or directed there by successive Cavendish Professors (Clerk Maxwell, Rayleigh, Thomson, Rutherford, and Sir Lawrence Bragg), have profoundly influenced the development of science. This article traces the progress of the Laboratory from its modest beginning in 1868 to its present position of pre-eminence.

It was in 1868 that the University of Cambridge took the first step towards the erection of a physical laboratory and the endowment of a separate department for the teaching of physics. In that year, a syndicate reported on the need for a physical laboratory, and the seventh Duke of Devonshire, then Chancellor of the University, came forward with an offer to provide funds for the building and for its equipment. This would be a rash offer at the present time for even the wealthiest of patrons, but in 1877 the first Professor was able to report that the Chancellor had 'completed his munificent gift to the University by furnishing the Cavendish Laboratory with apparatus suited to the present state of science.'

FIGURE 1 – *James Clerk Maxwell, Cavendish Professor* 1871–79.
*(By permission of Longmans, Green & Co. Ltd.)*

The Chair of Experimental Physics was founded in 1871, and in honour of the Duke's famous but eccentric kinsman, Henry Cavendish (1731–1810), it became the Cavendish Professorship. The choice of the first Professor was an important one, and, after some hesitations, it fell upon James Clerk Maxwell. Maxwell had already made a reputation for himself as Professor at King's College, London. In the realm of theory he had made considerable contributions to the kinetic theory of gases, to the explanation of the nature of Saturn's rings, and to the theory of the propagation of electro-magnetic waves. He had also carried out experiments on colour mixture, on the viscosity of gases, and on the ratio of electrical units.

Immediately on his appointment he made a tour of such laboratories as existed, and picked up what information he could as to planning and equipment. The building was ready for partial occupation in 1873, and was formally opened in 1874. It was designed for two types of experimental work, which Maxwell carefully distinguished in his inaugural lecture—experiments of illustration and experiments of research. The former were of the nature of demonstrations, more like our modern lecture demonstrations than an organized course of practical instruction, and were qualitative rather than quantitative. It was only in the Long Vacation of 1879 that a course was introduced which was the precursor of 'practical physics' as now understood. In this course it was proposed to 'perform before the class such experiments and make such measurements

as are ordinarily required in physical investigations.' Subsequently the apparatus was to be turned over to the class so that they might repeat the experiments.

The other type of experiment which Maxwell forecast in his inaugural lecture was research in the modern meaning of the term. The most important research carried on in the laboratory in Maxwell's time was probably the work on electrical standards, which he had begun while at King's College in 1862. The work was done under the auspices of the British Association, and was carried on throughout Maxwell's Professorship, and later under his successors, until the establishment of the National Physical Laboratory, when it was transferred to that institution.

In the research work of the laboratory Maxwell took little part, and he lectured to comparatively small classes. In 1876 he advertised a course of lectures in Heat and Light for Part I of the Natural Sciences Tripos, for which, according to the notice, nothing more was required in the way of mathematical equipment than a knowledge of arithmetic. How seriously Maxwell took this limitation we can only conjecture, and the published syllabus raises considerable doubts!

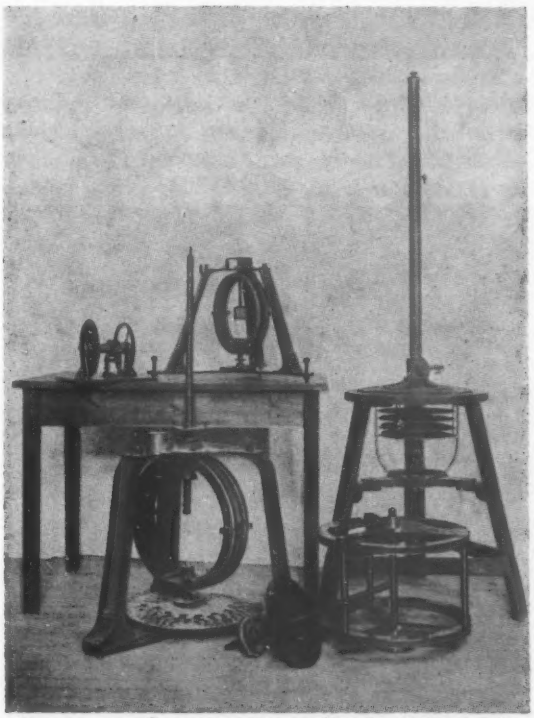


FIGURE 2 – *Some apparatus used in classical researches.*
*(By permission of Longmans, Green & Co. Ltd.)*

There was one major task which Maxwell carried out with great conscientiousness and much labour. Henry Cavendish had done interesting and valuable original work in electricity, but, owing to his dislike of fame or notoriety, it had remained unpublished from the time of his death in 1810. His papers were passed on to Maxwell, who set himself to edit them and prepare them for publication.

Among the numerous experiments which Maxwell performed in this connection was the measurement of electric discharges by the only effect which was available to Cavendish for the purpose—the physiological one. The two terminals of the circuit were introduced into two bowls of water, and the human galvanometer then took the shock by inserting one hand into each bowl. From the intensity of the sensation he gauged the strength of the discharge.

Maxwell died in 1879, at the early age of 48. In the Cavendish Laboratory today we still have some relics of his time. There is still preserved—more carefully now than at one time—a good deal of the apparatus which he left to the Laboratory. This includes the apparatus used by him for the study of the viscosity of gases, his apparatus for colour mixture, two dynamical spinning tops, a model of Saturn's rings, and an electroscope which had belonged to Wollaston.

Maxwell had come to the Cavendish Chair with an established record as a professional teacher and research worker. The next occupant came as an amateur. The Hon. R. J. Strutt had been at Cambridge when the Chair was instituted, and had been partly instrumental in persuading Maxwell to accept the appointment. He had inherited the title of Lord Rayleigh, and was residing at his country estate at Terling in Essex, where he had equipped a laboratory for himself. He had had a brilliant record at Cambridge, and had made original contributions of distinction. In December 1879 he was elected to the Professorship, and immediately took up his duties.

He was extremely dissatisfied with the equipment which he found. Probably little had been added to the original equipment and there were obvious gaps. Rayleigh was no devotee of the instrument maker. He always used the simplest and most primitive apparatus which would serve his purpose, and it was probably he who instituted the tradition of 'glass, sealing wax, and string'

FIGURE 3 – *The entrance of the Cavendish Laboratory, showing extension in the distance.*
*(By permission of Longmans, Green & Co. Ltd.)*

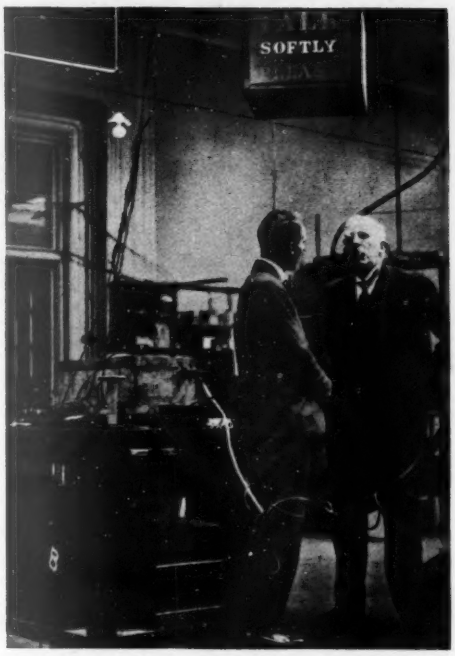



FIGURE 5 – *Lord Rutherford with one of his staff (J. A. Ratcliffe).*
*(From Rutherford, by A. S. Eve, Cambridge University Press.)*

FIGURE 4 – *Research Students*, 1909. *(By permission of Longmans, Green & Co. Ltd.)*

*Top row:* L. Vegard, G. Stead, J. R. Wilton, H. H. Paine, G. I. Taylor.
*Second row:* H. Thirkill, R. Whiddington, L. Southerns, J. M. Adams, E. M. Wellisch, C. S. Wright, R. T. Beatty.
*Third row:* G. W. C. Kaye, T. H. Laby, H. Erikson, W. Borodowsky, H. V. Gill, D. M. Bose.
*Fourth row:* J. A. Crowther, F. Horton, D. B. Pearson, Sir J. J. Thomson, E. R. Laird, N. R. Campbell, J. Satterly.
*Bottom row:* A. Ll. Hughes, J. A. Orange, R. Kleeman.

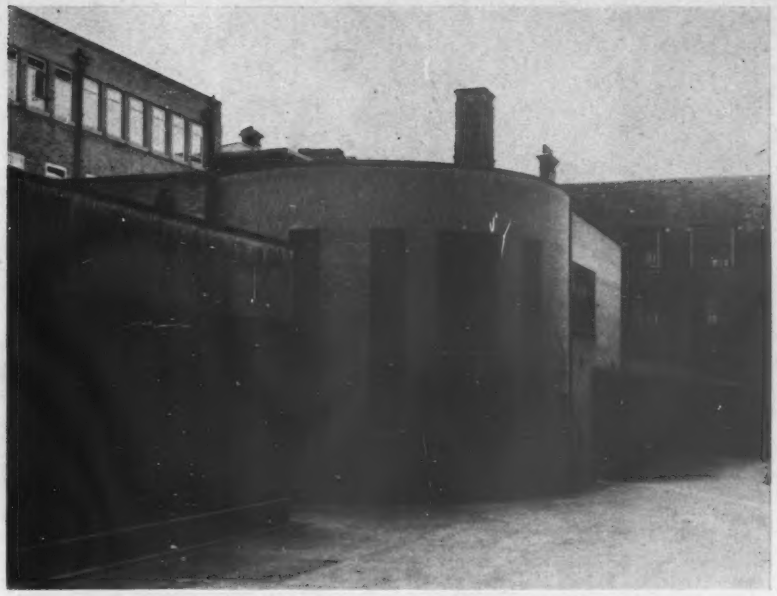


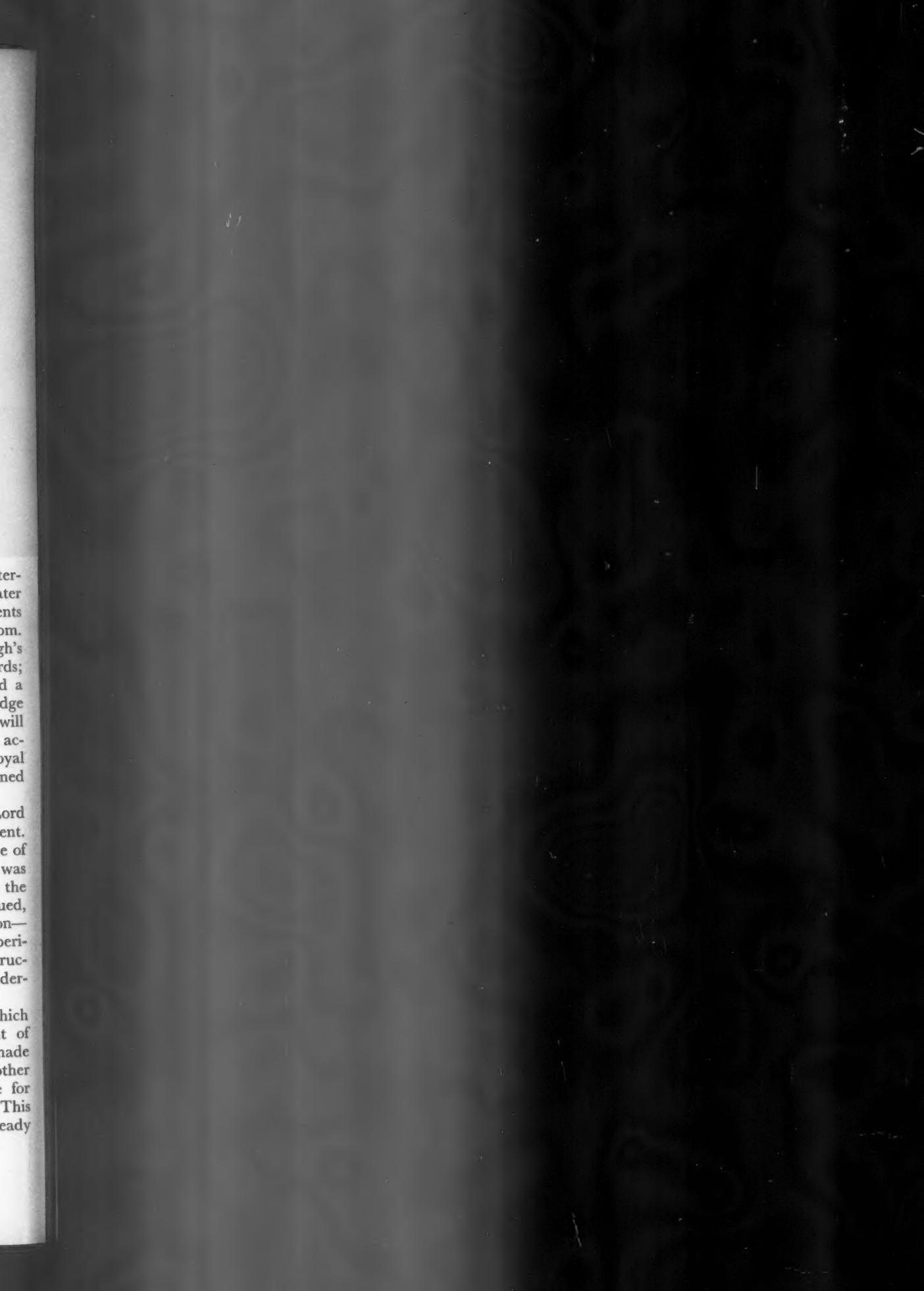
FIGURE 6 – *The Royal Society Mond Laboratory.*

which became characteristic of the laboratory. All the same, his lifelong interest in acoustics led him to point out that the laboratory possessed no musical instrument and—a more fundamental omission—was without a 'prime mover.' Rayleigh immediately raised a fund for equipment, and was himself a generous contributor. He also instituted the workshop, that invaluable adjunct of a laboratory, the general usefulness of which has steadily increased with the passing years. In the teaching of the laboratory he introduced no great changes. He took his share in the lecturing and in the practical classes, now increasing in size: the demonstrators Glazebrook (afterwards head of the National Physical Laboratory) and Shaw (afterwards head of the Meteorological Office) developed the system of instruction by manuscripts which has been in operation ever since, and has provided the material for Glazebrook and Shaw's *Practical Physics*, Bedford's *Practical Physics* and Searle's *Experimental Elasticity* and *Experimental Optics*. It was also during Rayleigh's time (1882) that women were first admitted to the laboratory.

Of Rayleigh's own work during his Professorship, the best known paper is that on the standardization of the ohm by means of the spinning coil. The apparatus he used is still in the Laboratory, and a brass plate marks the brick pillar in the end room on the ground floor where the coil was erected. Here, too, in later times stood the apparatus used by J. J. Thomson for the determination of the charge on the electron; and later still that used by Rutherford in his experiments on the disintegration of the nucleus of the atom. The chief interest of the Laboratory in Rayleigh's time was the determination of electrical standards; but his own work throughout his life showed a catholicity of taste and a breadth of knowledge which, owing to increasing specialization, will never again be attained. In 1884 Rayleigh accepted the position of Professor at the Royal Institution, a much less onerous post, and resigned from the Cambridge Chair.

The vacancy created by the resignation of Lord Rayleigh was filled by a surprise appointment. Joseph John Thomson, upon whom the choice of the electors fell, was only 28 years of age, and was regarded primarily as a mathematician. That the choice was a wise one need not now be argued, in spite of the fact that in one sense Thomson—universally known as 'J.J.'—never was an experimental physicist. He had no skill for the construction or manipulation of apparatus, but he understood it, and all his interests were physical.

In 1894 the University took a step which affected the whole subsequent development of Cambridge science. The B.A. degree was made available to students who were graduates of other Universities, and who came to Cambridge for two years of 'advanced study' or research. This opened a new door through which flowed a steady



stream of 'research students,' not only from other British Universities, but from the Dominions, the United States, India, and many other countries. The first to arrive at the Cavendish were Ernest Rutherford from New Zealand, Townsend and M'Clelland from Ireland, and Craig Henderson from Glasgow. Steadily 'J.J.' built up a research school from the physicists thus made available, until at the outbreak of war in 1914 he had about forty post-graduate research students working under his direction. It was generally he himself who suggested the subject of research, and he gave almost daily supervision to its progress. Most of the problems were associated with the nature and mechanism of the conduction of electricity through gases, and there was a delightful personal relationship between 'J.J.' and his team.

Thomson's own outstanding contributions were the identification of the electron in its various manifestations, the measurement of its mass and charge, and the exposition of the mechanism of electrical conduction in gases. These achievements were popularly recognized by describing Thomson as 'the man who split the atom.' His later work on positive rays was important, but was a contribution rather than a completed investigation.

In 1908 the Laboratory was extended through a benefaction by Lord Rayleigh who gave for the use of the Cavendish the value of the Nobel Prize which he had received that year. With the outbreak of war in 1914 all development came to an end; indeed this was the end of an epoch, for in 1918 J. J. Thomson was elected Master of Trinity, and in 1919, owing to the accumulated duties which faced him as the Head of a great college, he resigned his Professorship, and, while continuing to work in the Laboratory, devoted himself mainly to the other claims on his time and interest. He not only established the reputation of the Cavendish as a place of research, but was a lucid and forceful lecturer, and contributed to the teaching side as well. He was knighted in 1908.

If the election of J. J. Thomson to the Cavendish Professorship in 1884 was a surprise, the election of Ernest Rutherford in 1919 was almost a foregone conclusion. First at the Cavendish as a research student, then as Professor at Montreal and later at Manchester, he had made a great reputation. In the field of radioactivity he had established the fact that a real spontaneous transmutation of the elements was in progress, and had interpreted the various radiations given out in the process. More, he had enunciated the nuclear theory of the atom. In many respects Rutherford carried on the tradition which had been established at the Cavendish, but not without developing and enriching it. He continued to attract post-graduate students from all over the world, and owing to the growth of physics as a subject in the Tripos at Cambridge, and the institution of the Ph.D. degree, he was able, in addition, to encourage an increasing number of post-graduate Cambridge students to undertake research. The key word was now 'the nucleus,' and a few months before taking up his duties Rutherford had succeeded in disintegrating the nucleus of the nitrogen atom by using $\alpha$-particles from radioactive sources as projectiles. Later, he was able to use artificially accelerated protons to produce changes in atomic nuclei and thus to achieve a partially controlled transmutation of elements.

It was a very great blow to the Laboratory, to the University, and to the whole scientific world when in 1938, in the full enjoyment of physical and mental vigour, he died after an illness of only a few days' duration. During his tenure of the Professorship there had been great changes in the department. In 1932 a new workshop was opened on the site of the old Engineering Laboratory; in 1933 a new electrical laboratory for teaching purposes was equipped; in 1934 the Crystallography Department was attached to the Cavendish; and in 1936 the new High Tension Laboratory was completed. In the meantime the brilliant work of P. Kapitza, the Russian physicist, on intense magnetic fields and very low temperatures led to the building of the Royal Society Mond Laboratory, of which Kapitza remained director until 1934.

But the most important addition to the resources of the Cavendish, although inspired by Rutherford's work and personality, did not mature until after his death. In 1936, Lord Austin offered the University 'securities to the value of approximately £250,000' to 'build and endow a very much needed addition.' Work on the site of the Austin wing was begun in 1938, and the building was completed with difficulty before the outbreak of war in September of that year.

In 1938 W. L. (now Sir Lawrence) Bragg was appointed to succeed Rutherford. He had been trained at the Cavendish, had made a considerable contribution to the development of sound ranging in the last war, and had established a great reputation in the field of X-ray crystallography. The immediate post-war years are bound to see immense developments in physics, and the Cavendish is ready to play its part in them.

# The flight of flying-fishes

G. S. CARTER

Although the flight of flying-fishes has long been studied by biologists, no satisfactory conclusion about its mechanism could be reached as long as observations were made only with unaided vision. Dr Carter, who has carried out original work on the subject, here shows how the solution of the problem has been advanced by the use of photographic methods for recording the flight and the application of aerodynamic principles in studying it.

The sight of flying-fishes gliding away from the disturbance caused by the passage of the ship is very common in any voyage across the warmer seas. Yet, however readily it may be observed, that fishes should be able to fly is still one of the most astonishing facts of nature. Naturally, it came early to the attention of biologists. It has long been, and still is, a favourite subject of discussion in natural history.

Though the flight can be very easily seen, accurate observation of it is difficult. All that can usually be seen with unaided vision is that the fish darts from the surface, glides for two or three seconds, breaking the surface in the earlier part of the glide but later free from it, and then splashes back into the water. Much discussion has centred round the question whether the flight is a simple glide or whether the wings are actively flapped like those of a bird. It is good evidence of the difficulty of observing the flight that naturalists were unable for many years to decide so elementary a question. Recently this and other disputed points have been settled by the use of better means of observation, such as the camera and cinematograph. We now know that the wings are never actively flapped, and we are able to give a fairly consistent account of most features of the flight.

The flight has other interests besides that of a very extraordinary biological adaptation. In using their wings as planes, these fishes make the nearest approach in nature to flight on the principles used by man. They are similar in general form to aeroplanes and must obey the same aerodynamic laws. It is thus of interest to try to interpret fish flight on aerodynamic principles. If we are not completely successful, it may be that there is still something to learn about flight from these fishes.

## STRUCTURE AND HABITS

The flying-fishes commonly seen from the deck of a ship are not the only fishes that fly. At least four types of fish fly or glide more or less expertly. But by far the most easily observed and the most adept at flight are the marine *Exocoetidae*, the common flying-fishes of the open oceans. We shall consider only this family, and among them only the best-adapted forms, such as *Cypselurus*, one of the genera most likely to be seen from a ship. In *Cypselurus*, in contrast to some other genera of the family, the pelvic as well as the pectoral fins are adapted for flight.

The *Exocoetidae* are fast-swimming fishes leading an active life near the surface of the sea, and feeding on smaller fishes and other members of the surface population. They are well adapted to such a life, being closely streamlined, much like a mackerel in form, and having large eyes (figure 2).

The adaptations to flight are numerous. The streamlined body is as suitable for flight in air as for rapid swimming. The ventral surface of the body is flattened, so as to give extra lift. The tail has taken on a form unusual in fishes. It is V-shaped, as is common among fishes, but the lower arm of the V is almost one-and-a-half times as long as the upper. This form of tail plays an essential part in the flight. Naturally, it is the paired fins, which form the wings in flight, that have undergone the most marked adaptation. The pectorals (figures 3 and 4) are about two-thirds of the body in length, and more than twice its ventral area when expanded. In swimming they are held closed against the body, but in flight they are advanced to a position nearly transverse to the body, and expanded (figure 7). Their dorsal surface is formed by a thin membrane. This is supported by 10–12 branching rays which project from the ventral surface of the membrane and have a peculiar backwardly-bent form in section (figure 4). A line joining the ventral edges of the rays forms with the membrane a good aerofoil section. The pelvic fins are much smaller and more or less quadrilateral in shape. Their structure is similar to that of the pectorals.

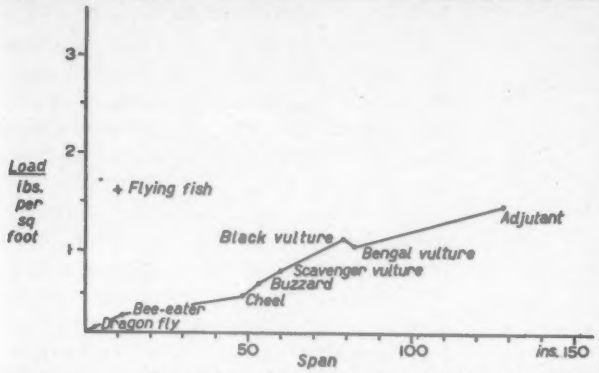



FIGURE 1 – *Comparison of the load and span of the wings in the flying-fish and in animals with flapping flight.* (*Redrawn from Hankin.*)

THE FLIGHT

At the start of a flight, the fish breaks the surface at its swimming speed, which has been estimated at 15–20 m.p.h. (figure 5*a*). Photographs have shown that the fish is almost exactly horizontal as it emerges (Edgerton and Breder) [3]. As soon as it is in the air, the pectorals are expanded, the pelvics being still held closed. This results—since the tail is less supported than the head—in the body taking on a considerable angle (about 15°) to the horizontal (figures 5*b*, 6), the large ventral lobe of the tail remaining in the water. For ½–1 second the fish 'taxis' along the surface in this position. As it does so, it vibrates its tail actively in the water (figure 6) at about 50 beats per second, and thereby increases its speed until air-speed is reached. Various estimates of this speed have been given—as low as 35 and as high as 55 m.p.h. Cinematograph photographs (Carter and Mander, 1935) [2] gave a speed of 25–30 m.p.h., but this was probably near the end of the glide owing to the difficulty of catching the early part with the camera. 40 m.p.h. is perhaps the best estimate of the initial gliding speed.

During the 'taxi' the vibration of the tail may set up a passive quivering of the front part of the body, and especially of the pectoral fins. It is probably this quivering that has led observers to state that the fins are flapped. There is no real evidence of active flapping during the 'taxi,' and it certainly does not occur during later parts of the glide, for the fins then show no haziness on photographs of even long exposure.

When air-speed is reached, the pelvics are expanded, the body becomes more nearly horizontal—a slope of about 6°—and the tail is lifted from the water (figures 5*c*, 7). In this position the fish glides at a nearly constant height of a foot or so above the water, losing speed. To maintain this height with decreasing speed, the inclination of the wings to the horizontal must be continually

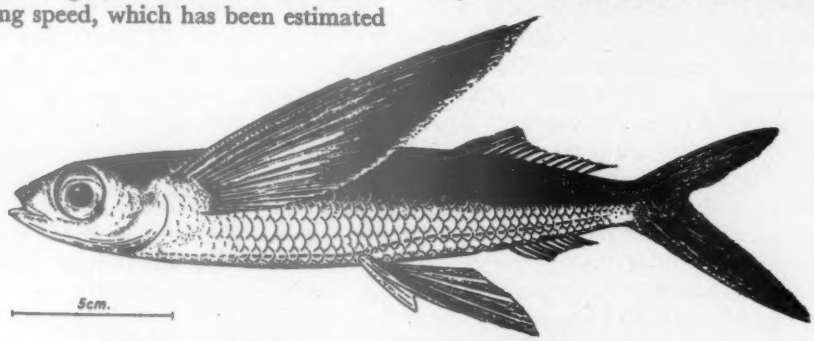



FIGURE 2 – Cypselurus lutkeni, *a typical flying-fish.* (*From Brown.*)

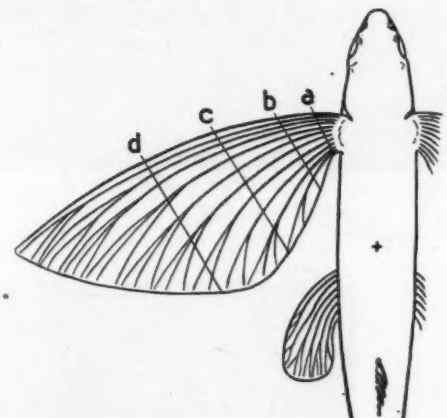



FIGURE 3 – *A diagram of the structure of a flying-fish as seen in dorsal view. Fins expanded. + marks position of the centre of gravity. a—d see figure* 4.

FIGURE 4 – *Transverse sections of the pectoral fins at the positions marked a—d in figure 3.*

increased. The fish has muscles capable of doing this. When air-speed is lost, either the fish falls back directly into the water, or the pelvics may be closed, the tail lowered and speed regained by vibrating the tail in the water (figure 5*d*). A further glide then follows (figure 5*e*). This last type of behaviour is very common, and as many as ten glides have been seen in a single flight.

The usual glide may last for anything up to 3 or 4 seconds, but is often much shorter. Hubbs, who made very many observations of the flight, gives an average of 2·6 seconds, excluding the initial 'taxi.' But glides of 10 or even 13 seconds have been recorded by good observers (Hubbs) [5]. These are definitely unusual. The length of the glide is naturally variable with the strength and direction of the wind. In still air an average glide is probably 40–50 yards, though estimates of 100 yards have often been made. The exceptional glides of 10 seconds are much longer. The speed at the end of the glide is about 25 m.p.h.

### AERODYNAMICS

It should be possible to find out how far and at what speed, on accepted aerodynamic principles, a fish could glide, by experiments in a wind-tunnel with either the fish itself or a model of it. This was first done by Shoulejkin (1929) [6], who used a model. He found that the model would fly at speeds over 23 m.p.h., and that with an initial speed of 34 m.p.h. it would glide for 6·2 seconds and 62 yards. This is a performance rather better than the normal glide, but by no means as good as the exceptional glides of 10 seconds or more.

However, a model can never accurately reproduce the structure of an animal. It will lack the finer details of structure and thus be much smoother, so that it will give less resistance and a longer flight. In particular, the wings of Shoulejkin's model were simple membranes, and it seemed to us that the peculiar structure of the wing as shown in figure 4 might affect the performance. For these and other reasons it seemed worth while to see how the fish itself would behave in a wind-tunnel[1]. But to make such observations presented some difficulties. We had only preserved fish, and the fin membrane shrinks during preservation, so that the preserved fin cannot be expanded to the area natural in flight. To get over this difficulty, the membranes were removed from both the pectoral and pelvic fins

[1] I owe the opportunity of making these experiments and much help in carrying them out to Dr L. G. Whitehead of Queen Mary College, University of London.

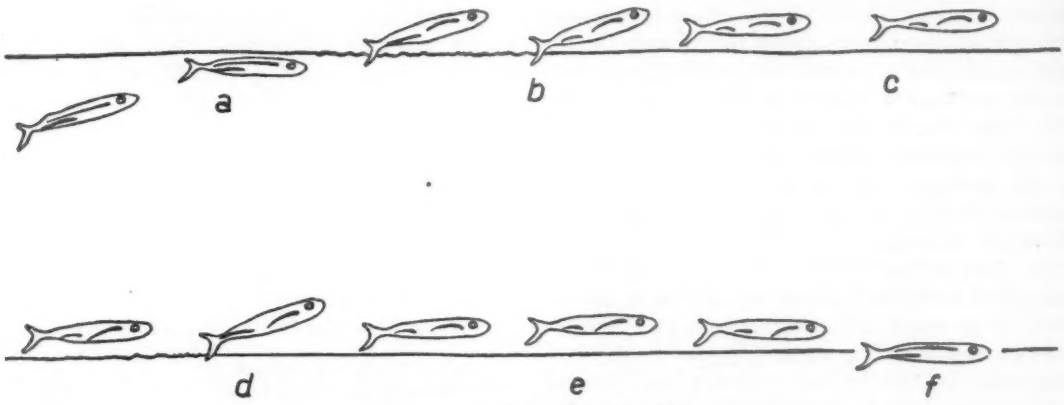



FIGURE 5 – *A diagram of a glide.*

*a. Position immediately before emergence.*
*b. The 'taxi.'*
*c. Glide with increasing angle of the wings.*
*d. Renewed 'taxi.'*
*e. Second glide.*
*f. Return to the water.*

FIGURE 6 – *A photograph of the fish during the 'taxi,' showing the angle of the body to the horizontal, closed pelvics, and the V-shaped trail left by the tail in the water.* (From Edgerton and Breder.)

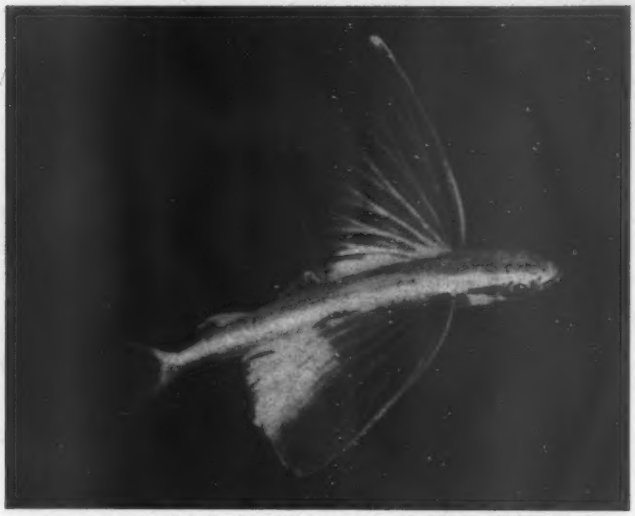


FIGURE 7 – *A fish in the glide, showing the form of the wings and expanded pelvics.* (*From Edgerton and Breder.*)

and replaced by cellophane of the required areas, the fin-rays being glued to the cellophane in their natural positions. The fins were kept expanded by threads attached to their leading edges and to pins driven into the body farther forwards. The fish was suspended by threads from the leading edges of the fins and from the body just in front of the tail.

Thus a fairly natural representation of the fish in flight was obtained. There was still the difficulty that the fins cannot be turned on the body in the preserved fish as they can in life. Shoulejkin had made no allowance for this. To obtain conditions more like the natural in this respect, we carried out two sets of observations. We first measured lift and resistance at different angles, turning the whole fish, both body and fins. We then removed the fins and repeated the observations with the body alone. By combining these two sets of observations we were able to calculate the performance with the fins at different angles and the body kept at 6° to the horizontal, as it is in the natural glide.

It is not to be expected that the fish as we mounted it should give as good a performance as in life, for the living fish will clearly be able to control the slope and camber of the wings much more accurately than we could do. Also, a living fish will probably be considerably smoother and give less resistance than a preserved one. Nor could we expect as good results as from Shoulejkin's smooth model. If his results were better than the natural, ours should be worse.

We found that the fish would fly above 25 m.p.h., and would have a flight of 1·74 seconds and 30 yards, with an initial speed of 40 m.p.h. Allowing for the better natural performance of the fish, it would seem that the normal glides (with an average of 2·6 seconds and 40–50 yards) are not longer than might be expected, but it is much less likely that the exceptional glides of more than 10 seconds can be explained without some further condition to improve the performance.

There is, however, a possible explanation. Aeroplanes, when close to the ground, are known to get extra lift owing to a cushioning effect on the air between them and the ground. The gliding fish is very close to the water surface and will probably get some help from this effect, but it is not possible on our present knowledge to estimate how great the help might be, or how it would vary with changing conditions.

The flight of flying-fishes is no doubt a means of escape from enemies. A flying-fish on emerging from the water would quickly pass out of vision of a pursuer (figure 8).

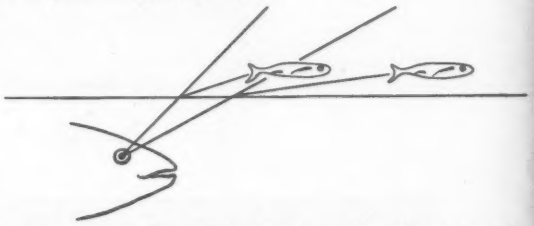


FIGURE 8 – *The effect of emergence on the vision of a fish pursuing a flying-fish.*

I owe my thanks to Dr Edgerton for permission to reproduce the photographs illustrating this article.

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# Artificial coat coloration and the growth of hair

ALEXANDER HADDOW and K. M. RUDALL

'And when we consider that other theory of the natural philosophers, that all other earthly hues—every stately or lovely emblazoning—the sweet tinges of sunset skies and woods; yea, and the gilded velvets of butterflies, and the butterfly cheeks of young girls; all these are but subtile deceits, not actually inherent in substances, but only laid on from without . . .'

Herman Melville: *Moby Dick*

During experiments on growth, which were designed to test a series of flavins prepared by Mr G. M. Timmis, we encountered [1] an undescribed property in one of these compounds (a derivative of alloxazine) [2], the structure and appearance of which are shown in figure 3. Unexpectedly, injection in albino rats of 20 or 30 mg. of this substance produced a yellow or orange-yellow pigmentation of the hair, not dissimilar in tint to that of the compound itself in moderate dilution. Some impression of this appearance is given in figure 1, showing a diffuse coloration on the back and sides, and again in figure 2, where the colour is most evident in a band along the flank.

The coloration is usually restricted to certain areas of the coat, in a way which varies in detail from one rat to another, but nevertheless conforms in all cases to a characteristic type of pattern, of which the most striking feature is a pronounced degree of symmetry about the longitudinal axis. Study of similarly injected animals from the same colony soon revealed the recurrence of pattern types, which it was comparatively easy to arrange as a roughly transitional series: these facts conveyed a strong impression of a certain unity of design, in which the pattern resulting from a single injection represents only one stage in a continuous process. The next problem concerned the nature of the pattern, and particularly whether it was a permanent characteristic of the individual animal. This question was soon disposed of, when we found that fresh zones of pigmentation appear in response to injections at intervals—that is, the form of the pattern differs, in the same animal, according to the time of administration of the compound. Hence its design depends upon some variable process, and not upon one which is fixed, or pre-determined, genetically or otherwise (*see* figures 4 and 5).

## RELATION OF PATTERN TO THE GROWTH OF HAIR

Postulating that the hair pigment might well be derived from the injected alloxazine, we then had to decide what the factors are which determine that the pigment will appear in certain areas, and not in others. A number of facts suggested that the underlying process might concern the regeneration of hair, and experiments were carried out to test this hypothesis. Normal rats were shorn on the back and sides, from the level of the ears to the root of the tail, and the subsequent course of regeneration was then plotted at intervals of a few days. Diagram I shows the outcome of one such experiment. It became apparent that only limited regions of the coat are regenerating hair at any given moment, that these areas are disposed in a symmetrical arrangement similar to the patterns revealed by injection of the *iso*-alloxazine, and that their variety is due to the varying rate of progress of the growth-wave front. It was further observed that the growth-wave cycle is complete in a minimum period of approximately six weeks. From these experiments it seems certain that the coat is replenished by a complex series of regular waves. About this time it was found that the alloxazine also induces coloration when administered in the food, and (supporting the above interpretation) that with continued feeding over several weeks the affected areas gradually expand until the entire pelage is fairly uniformly pigmented. Furthermore the nursing female, when given the compound in her diet, is able to transmit the pigment by the milk to her offspring. In this case the young develop an almost generalized coloration from the beginning, since the first coat emerges almost uniformly, its renewal by regions not becoming established until later. One such rat which received the

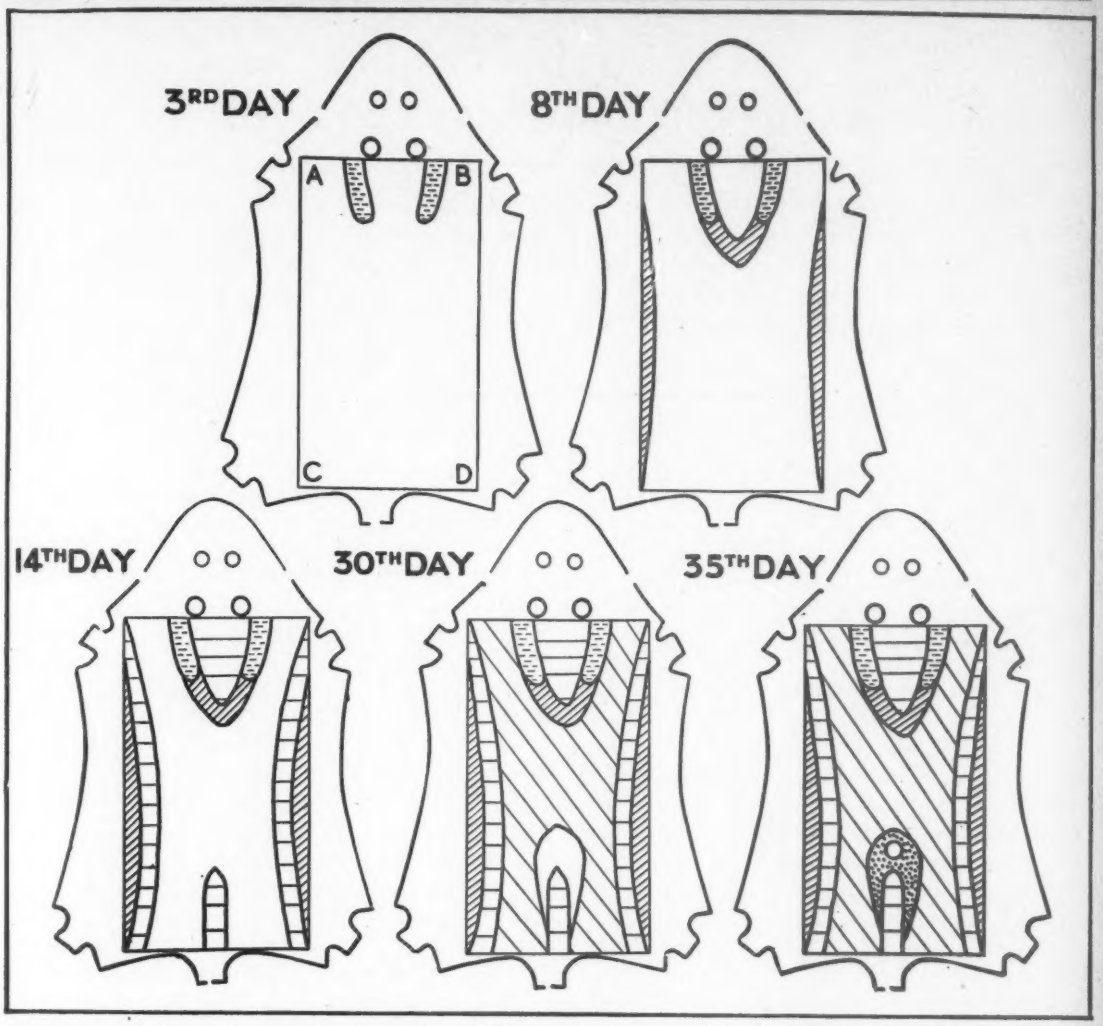



DIAGRAM 1 – *Schema to show the regeneration of hair at* 3, 8, 14, 30, *and* 35 *days after shearing the area ABCD in a single rat. At day* 3, *growth is confined to two strips entering behind the ears. Five days later these have converged and fused in the mid-line, while new tracts of regeneration are appearing laterally. By day* 14 *these have further advanced, the area enclosed by the anterior fork has become covered, and growth has taken place along a narrow wedge extending from the root of the tail. Sixteen days later the lateral wave fronts have merged over a considerable distance, and regeneration is complete at day* 35, *save only for a small island in the mid-line. Thus similarly hatched areas are those in which hair is growing at the same time and in which the alloxazine pigmentation would develop in response to administration of the compound at about that time. It will be noted that the process is highly symmetrical throughout.*

alloxazine *via* the milk from the seventh day following birth, and ingested it in the solid diet for a considerable period after weaning, is seen in figure 6.

### NATURE OF THE HAIR PIGMENT

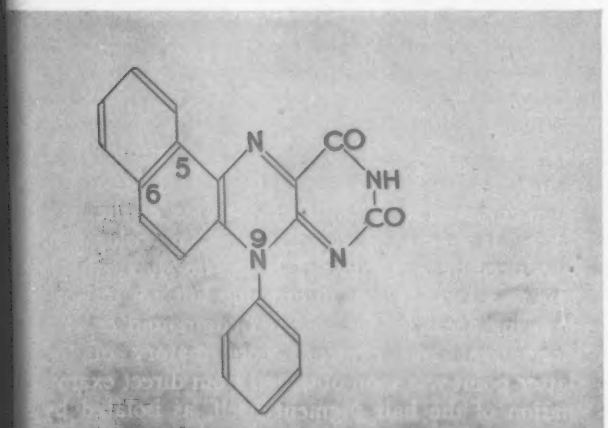
Here figure 7 is of interest, showing a cross-section of hair in a pigmented area, from an animal which had been given a single injection. Two points will be noted. First, that only a proportion of the hairs (presumably those in active growth) show yellow pigment; secondly, that the pigment is to be found in the cortex of the hair fibre. It now appeared that the hair coloration produced by 9-phenyl-5 : 6-benzo-*iso*-alloxazine is due to a localization, in growing but not in non-growing areas, of the injected compound or of a derivative; and evidence confirmatory of the latter point was soon obtained from direct examination of the hair pigment itself, as isolated by Dr L. A. Elson.

FIGURE 1

FIGURE 2

*These albino rats had received an intraperitoneal injection of 25 mg. of the phenyl-benzo-alloxazine two weeks earlier, the orange-yellow coloration becoming obvious about a week following injection. The unusually diffuse coloration shown in the rat on the left should be compared with the more restricted distribution in that on the right, in which the pigmentation was confined to a lateral tract on either flank.* (By courtesy of Kodak Research Laboratories.)

In order to recover the pigment, several grams of the coloured hair were heated in glacial acetic acid. After cooling, chloroform was added, the mixture filtered, and the filtrate washed with water. The chloroform layer was then separated, dried with sodium sulphate, and chromatographed on alumina (Spence—Type H). In ultra-violet light the chromatogram showed a strongly adsorbed yellow band, depicted in figure 13; this was removed from the column by means of chloroform containing 1 per cent. of glacial acetic acid, and the solution again washed free from acid, dried, and filtered. The ultra-violet absorption spectrum of this extract was then examined by Dr E. M. F. Roe, and compared first with that of the injected compound, and secondly with the spectrum of an extract similarly prepared from normal hair. The result is shown in figure 12. From this it is concluded that the spectrum of the yellow fluorescing eluate shows the presence of the original compound, or of some simple derivative indistinguishable from it under the conditions employed. By this means it was also calculated that there is approximately 0·1–0·2 mg. of 9-phenyl-5:6-benzo-*iso*-alloxazine in the fluorescent eluate from 1 gm. of hair.




9-PHENYL-5:6-BENZO-*ISO*-ALLOXAZINE

FIGURE 3 – 9-*phenyl*-5:6-*benzo*-iso-*alloxazine: the formulation and colour of the actively pigmenting compound.*

### MECHANISM OF LOCALIZATION

Both the origin and localization of the hair pigment had now been virtually proved. The probable *mechanism* of localization was deduced from further experiments in which the capillary system was made visible by the intravenous injection of chlorazol sky-blue. Figure 8 shows the skin of a normal rat which had been sheared some days before; in this case, regeneration was proceeding towards the mid-line equally on both sides when the animal was injected with chlorazol sky-blue and killed. In figure 9 we see the under-surface, from which it is clear that the greatest density of capillaries occurs in those positions which correspond to the advancing edge of the growing hair. This observation is believed to be entirely new, and suggests that the moving patterns of hair-growth

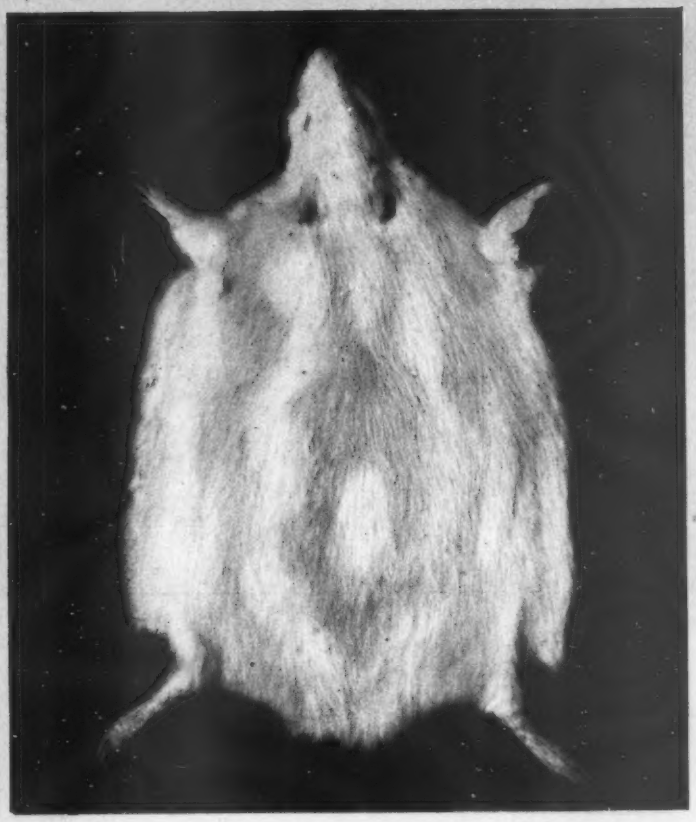


FIGURE 4 – *Rat pelt* ($\times 1/2$) *to show symmetrical coloration produced by two intraperitoneal injections (at an interval of one week) of 25 mg. of 9-phenyl-5:6-benzo-iso-alloxazine in arachis oil. Observation of the results of such spaced injections proved that the pattern elicited is not a fixed character of the individual animal, but varies with the time at which the alloxazine is injected.*

FIGURE 7 – *Cross section of hair* ($\times$ 400) *from a coloured a in a rat which had received a single injection. Only a proportion the hairs contain the pigment, which is diffused throughout the cort*

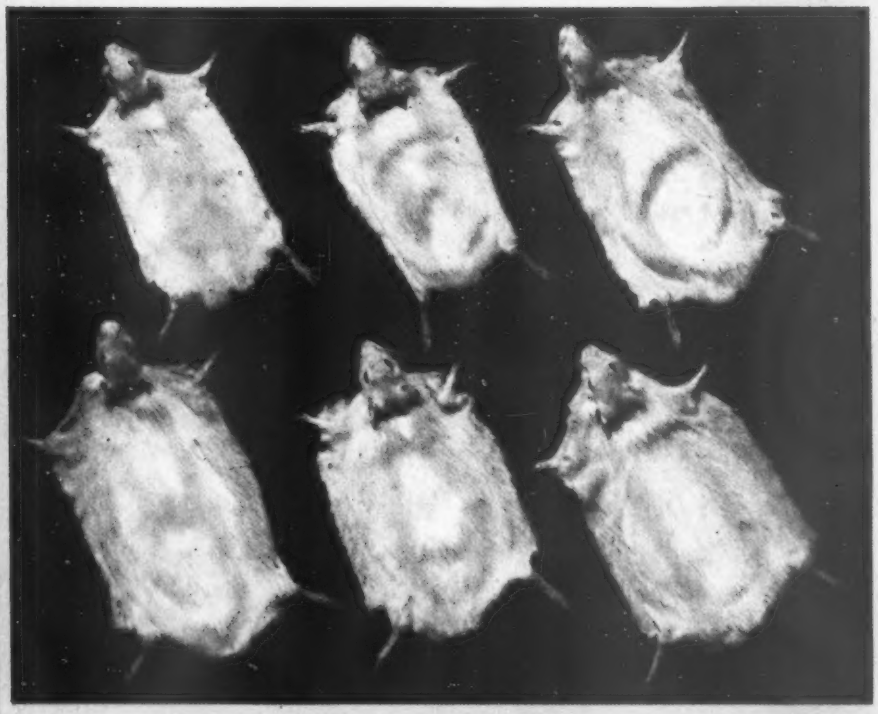


FIGURE 6 (*above*) – *Coloration originally induced by absorption of the alloxazine from the milk—the mother of this young rat having been given the compound in her diet, starting a few days after the birth of her litter. Oral administration of the compound itself was subsequently continued after weaning. Note the exceptional depth and intensity of pigmentation, and its wide distribution.*

(*Photograph by Mr. Frank Goulden, A.R.I.C.*)

FIGURE 5 (*left*) – *A range of pelts from rats given two doses of the alloxazine at an interval of one week, arranged to illustrate the variety of individual pattern forms and the presumptive relation between them as members of a series* ($\times 1/4$).

FIGURE 8 – *Skin of a normal rat sheared some days before. Regeneration of hair was proceeding uniformly from both sides towards the mid-line when chlorazol sky-blue was injected intravenously and the animal killed.* ($\times$ 2/5).

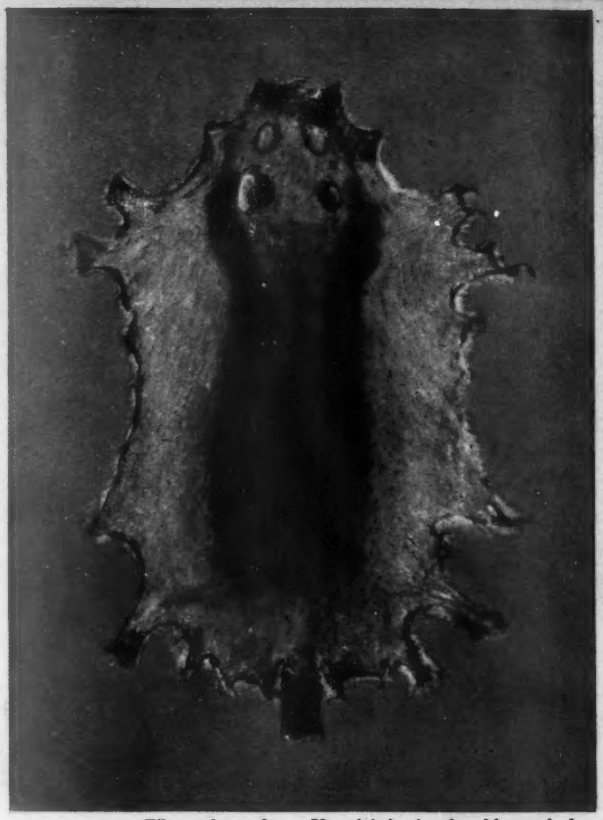


FIGURE 9 – *The undersurface. Vessel injection by chlorazol sky-blue shows that the highest density of capillaries occurs in the positions corresponding to the advancing edge of the growing hair, as seen in figure* 8. ($\times$ 2/5).

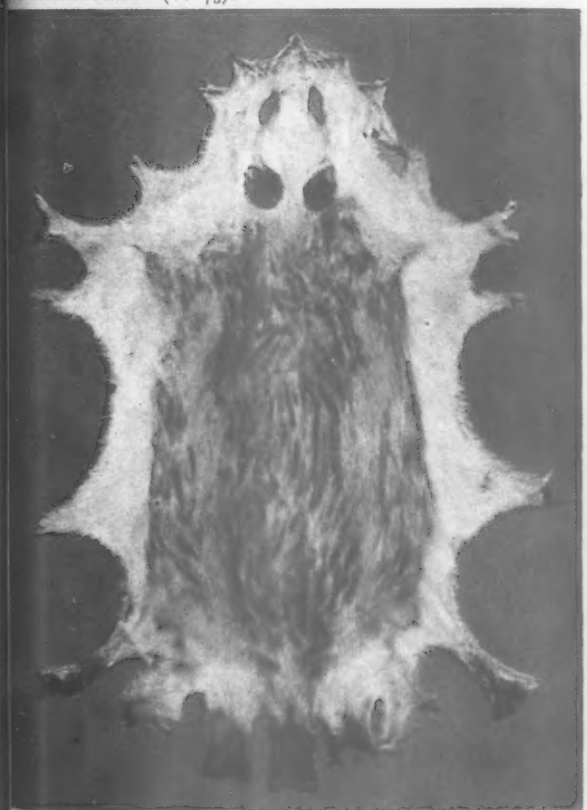


FIGURE 10 – *Skin of a rat first sheared, then injected intraperitoneally with the alloxazine and subsequently with chlorazol sky-blue intravenously within a few days. Pigmentation is beginning to appear in the areas showing active growth.* ($\times$ 2/5).

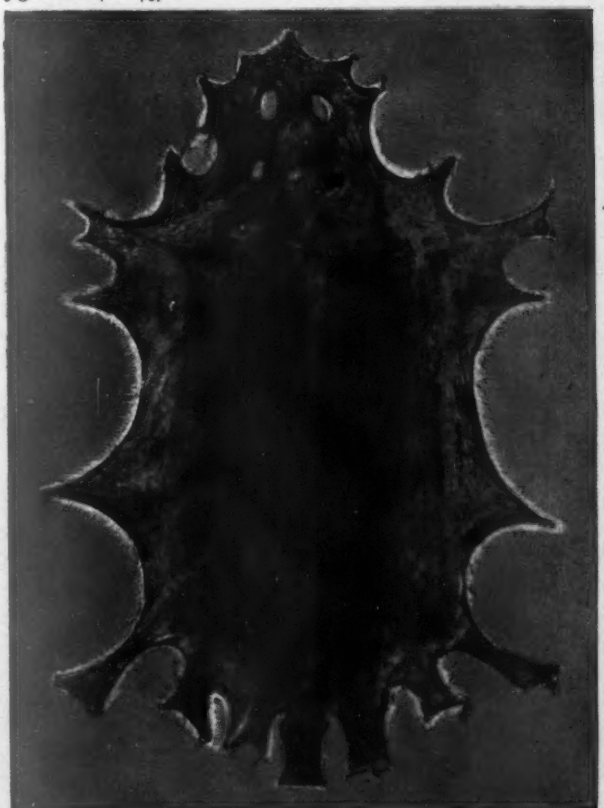


FIGURE 11 – *The undersurface. Maximum capillary density has the same distribution as that of the growing hair and the pigmented tracts as shown in figure* 10. ($\times$ 2/5).

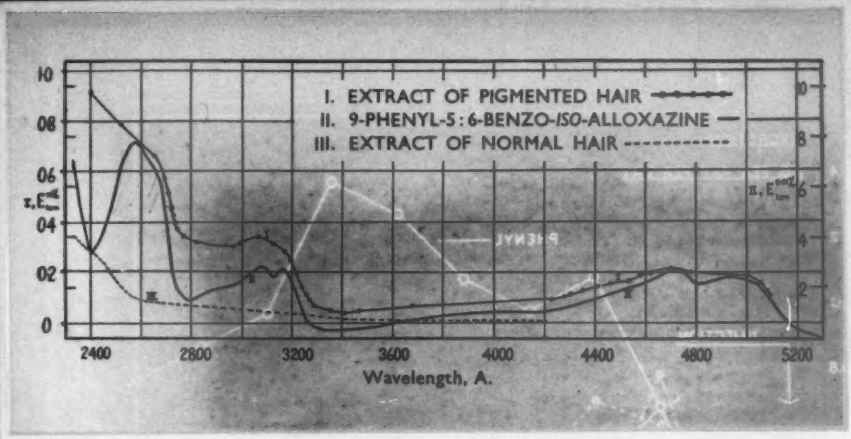



FIGURE 12 – *Comparison of the absorption spectrum of 9-phenyl-5:6-benzo-iso-alloxazine with the spectrum of an extract of coloured hair (in chloroform), and with that of a control extract of normal albino hair. These measurements indicate that the pigment entering the hair after administration of the alloxazine is either the compound itself or a spectroscopically indistinguishable derivative.*

FIGURE 13 – *Fluorescence (in ultra-violet light) of the strongly adsorbed pigment recovered by chromatography on alumina from a final chloroform extract of pigmented hair.* (*Photograph by Miss Hilda Robertson, Royal Cancer Hospital.*)

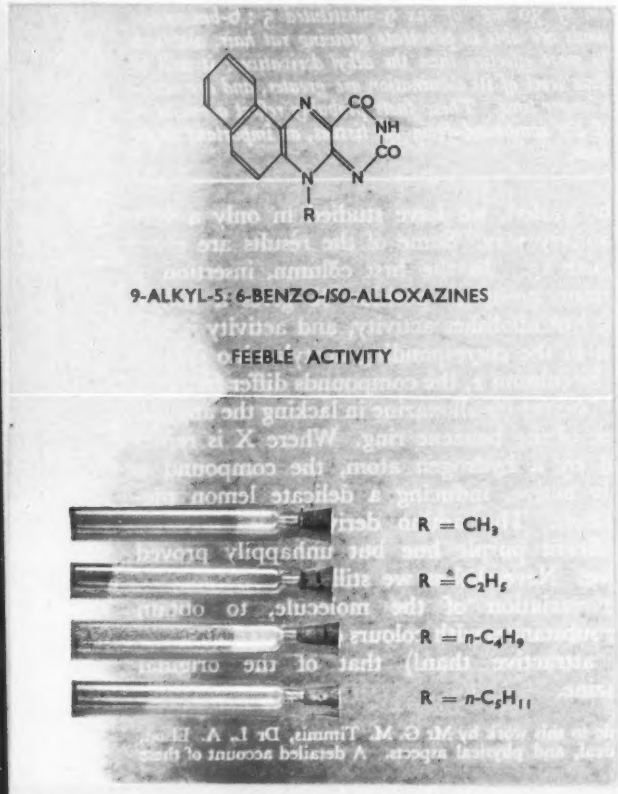



FIGURE 14 – *9-alkyl-5:6-benzo-iso-alloxazines—examples of compounds with only slight activity.*

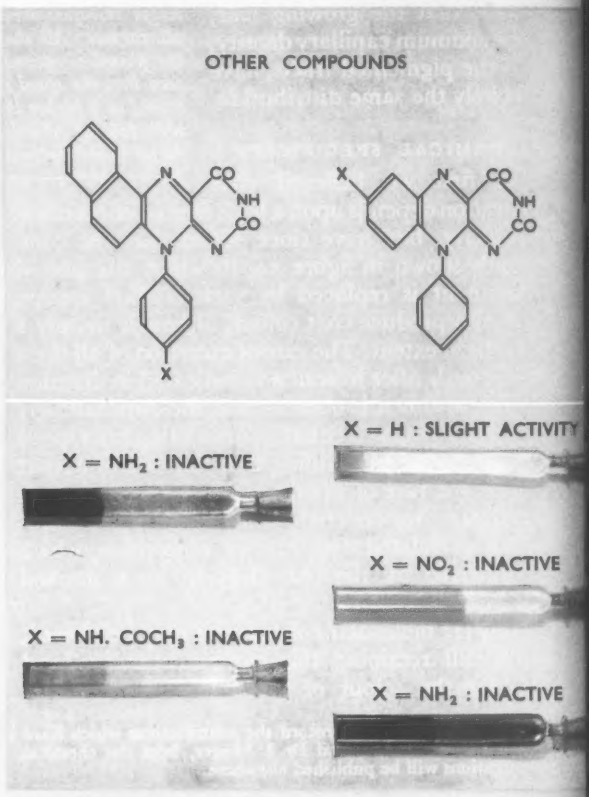



FIGURE 15 – *The results of tests with other compounds, derivat of 9-phenyl-iso-alloxazine or 9-phenyl-5:6-benzo-iso-alloxazine.*

appear in response to alterations in the distribution of blood to the hair follicles. It is also likely that the pigment enters growing areas partly because these are the only ones in sufficiently active interchange with the general circulation. This interpretation was confirmed by rendering the capillaries visible in rats which had been not only sheared, but injected with the alloxazine as well. Figure 10 shows the skin of such an animal in which, once more, pigmentation is beginning to appear in those areas alone which are showing active growth. In figure 11, again, we see the under-surface of the same skin, and it is apparent that the growing hair, the maximum capillary density, and the pigmented tracts, have precisely the same distribution.

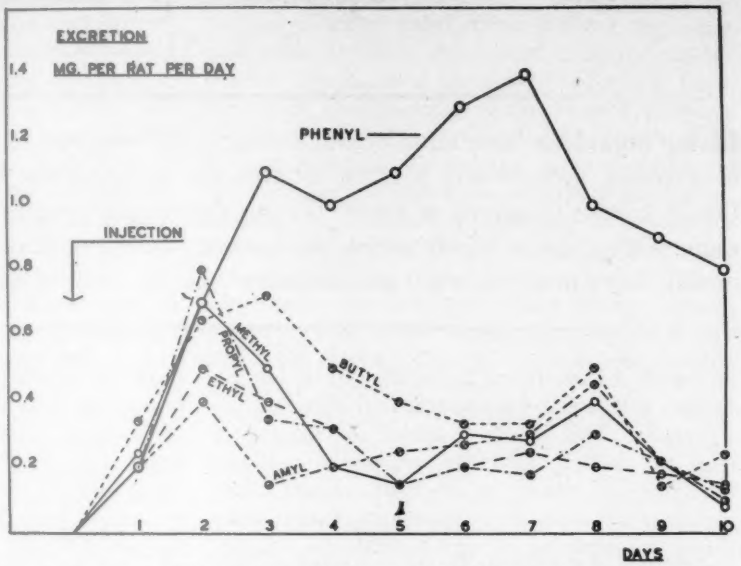



DIAGRAM II – *The excretion of pigment in the faeces and urine following a single intraperitoneal injection of* 30 *mg. of six* 9*-substituted* 5 : 6*-benzo-iso-alloxazines. All these compounds are able to penetrate growing rat hair, although the phenyl compound is vastly more effective than the alkyl derivatives: it will be seen that the speed and absolute level of its elimination are greater, and are maintained at a higher level for a longer time. These facts probably reflect a considerable rate of absorbability of the compound from the tissues, an important single factor in its biological behaviour.*

### CHEMICAL SPECIFICITY

At first we believed that coloration depends upon a high degree of chemical specificity, but have since found that the compounds shown in figure 14, in which the phenyl substituent is replaced by various alkyl groups, may also produce coat colour, although to only a very slight extent. The rate of excretion of all these compounds after injection is indicated in diagram II. From this it is obvious that the outstandingly active compound is equally outstanding in its speed of elimination. Assuming that the rate of output reflects the rate of uptake of the compound from the tissues, we conclude that intensity of coloration is correlated with ease of absorption, which is conferred by the phenyl group to a marked degree.

How far molecular constitution may be altered, while still retaining this curious property, and how far the colour of the pigments themselves can be varied, we have studied in only a very preliminary way. Some of the results are given in figure 15. In the first column, insertion of an amino group at position X gives a brown colour but abolishes activity, and activity is also absent in the corresponding acetylamino derivative. In column 2, the compounds differ from the phenyl-benzo-*iso*-alloxazine in lacking the angular residue of the benzene ring. Where X is represented by a hydrogen atom, the compound is slightly active, inducing a delicate lemon pigmentation. The amino derivative possesses a magnificent purple hue but unhappily proved inactive. Nevertheless we still hope, by appropriate variation of the molecule, to obtain active substances with colours differing from (and more attractive than!) that of the original alloxazine.

It is a great pleasure to record the contributions which have been made to this work by Mr G. M. Timmis, Dr L. A. Elson, Miss Edna M. F. Roe, and Dr I. Hieger, from the chemical, biochemical, and physical aspects. A detailed account of these investigations will be published elsewhere.

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# Specific poisons

R. E. SLADE

Living organisms have idiosyncratic reactions towards various chemical compounds, and it is therefore theoretically possible to discover or synthesize specific poisons for any particular species of animal or plant. To put theory into practice, however, proved a difficult undertaking, and it is only within the last ten years or so that substantial progress has been made. Even now, the exact mechanism of specific toxicity is not properly understood.

The work of Pasteur and Lister showed that many diseases are caused by bacteria and other micro-organisms. This led to a search for substances able to destroy infecting organisms without damaging the tissues of the body. Lister chose phenol as the substance possessing the most satisfactory combination of high bactericidal activity and low toxicity towards human tissues. By means of phenol the main sources of infection, such as surgical instruments and dressings, can be effectively sterilized. Phenol is, however, of limited value for attacking bacteria in the body itself. Although it can be used for local infections its toxicity is too high to permit its introduction into the blood stream for combating general systemic infections.

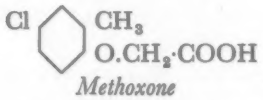
Ehrlich was the first to discover a poison which was sufficiently specific in its action to be used therapeutically for general infections. He found that certain arsenical poisons would destroy the spirochaete of syphilis without killing the patient. The margin between the dose lethal to the spirochaete and that harmful to the patient was, however, so small that the use of these drugs was not entirely satisfactory. The success of the arsenical compounds led Ehrlich and his school to the investigation of the toxicity of thousands of other substances, particularly dyes. This resulted in the discovery of atebrin, which possesses specific toxicity towards the trypanosomes of malaria. In 1935 it was found that prontosil rubrum, a dye, was able to destroy streptococci in the blood stream. Shortly afterwards, Fourneau found that when this dye was reduced it split into two components, and that the toxic effect was due to one of these, namely sulphanilamide. From sulphanilamide has been developed a wide range of other sulphonamides possessing anti-bacterial properties.

Before the discovery of the sulphonamides, Fleming (1928) had shown that the culture medium in which the mould *Penicillium notatum* had grown was able to kill and lyse certain kinds of bacteria, particularly staphylococci. Several years later (1938), this problem was closely investigated by Florey and Chain, who were able to isolate penicillin, the active principle of the culture medium. This substance is highly specific in its action. It combines a very high toxicity towards Gram-positive bacteria, such as streptococci and staphylococci, with a negligible toxicity towards animal tissues. In this respect it is therefore an almost ideal chemotherapeutic agent. Several other anti-bacterial mould products possessing a relatively specific action against bacteria have also been isolated, but none is so specific as penicillin and their therapeutic value is limited.

Since man learnt the art of cultivating crops, the problem of checking the growth of weeds has been of importance. Until quite recently the control of weeds has been largely mechanical, as by ploughing them in or removing them by hoeing. Within the last few years however, substances have been found which will specifically poison many kinds of weeds without harming certain of the important cereal crops. In 1934, Kögl, Haagen-Smit, and Erxleben found that urine contains a plant growth substance similar to the auxins. They called this substance hetero-auxin and identified it as β-indolyl-acetic acid.

Wendt had already shown that the auxins performed certain essential functions in plant life, and called them 'growth substances.' One remarkable action of the auxins is the way in which a minute amount applied to the side of a growing stem will cause it to bend over to the other side in a few hours. In larger quantities it causes rootlets to grow on the stem. Further investigation showed that related substances, such as α-naphthyl-acetic acid, possessed similar biological properties.

In 1937, Grace, in Canada, found that on certain soils lettuce crops could be increased by as much as 300 per cent. by applying α-naphthyl-acetic acid at the rate of 150 mg. per acre. He found also that larger applications depressed the yield. In this country Templeman and Marmoy confirmed Grace's finding that large applications depressed the yield, but on their soils they could not confirm the beneficial effects of small quantities. Slade and Templeman decided to try α-naphthyl-acetic acid for controlling the growth of charlock in corn crops, and Templeman found that, applied at the rate of 25 lb. per acre, it was extremely effective in killing charlock, but had little or no effect on wheat, oats, or barley. This specificity was expected, for the growth substances behaved very differently in causing root-growth of cuttings of different plants; and the toxicity was not surprising in view of the fact that α-naphthyl-acetic acid can cause most abnormal growth in plants even in minute quantities. Application of large quantities of α-naphthyl-acetic acid as a weed-killer is too costly for general use, but it has since been found that many other substances possess similar properties. Templeman found that several substances in a range prepared by Sexton were far more toxic to weeds than α-naphthyl-acetic acid, and were still harmless to cereal crops at concentrations which killed weeds. One of these compounds, 2-methyl-4-chloro-phenoxy-acetic acid has been developed as a commercial weed-killer under the name 'methoxone.'




*Methoxone*

This compound will kill most of the weeds in corn crops when applied at the rate of ½ to 2 lb. per acre. It seems that all these compounds which act similarly to the plant growth substances contain some structural feature of the molecule which is identical in all cases, and that this portion of the molecule causes them naturally to enter into certain reactions taking place in the plant cell.

The auxins, the natural growth substances of plants, are known to have several effects on plants. They do not affect cell division but cause a plastic extension of the cell wall; the cells then elongate by osmosis. Auxins cause the shoots of plants to grow upwards and the roots downwards. They cause plants to bend towards the strongest light. When present in the soil they inhibit root growth. In view of these varied effects it is not surprising that when synthetic substances having a similar effect are supplied to the plant in relatively large quantities, the economy of the plant is seriously disturbed. It is not yet possible, however, to account satisfactorily for the great variation in the sensitivity of plants towards these substances. It is possibly related to differing capacities for absorbing them into the protoplasm. Their value as weed-killers is due to the fact that monocotyledons, the family to which grasses, wheat, oats, rye, and barley belong, are in general very much less sensitive than the dicotyledons growing with them as weeds.

Many insects are troublesome pests. Flies, mosquitos, fleas, lice, and bed-bugs are among those which trouble man. Ticks, keds, blowflies, fleas, and lice attack animals. Locusts, weevils, mites, and aphides destroy crops, whilst moths, weevils, and cockroaches destroy stored products. There is therefore an urgent need for poisons which will destroy insects, but if these are to be used on a large scale their action should be specific. They must not be poisonous to men or animals, and must not damage the foliage or flowers of plants when used in the form of a spray or dust.

Pyrethrum flowers were known to the Arabs as destructive of insects and worms, but it is only during the last 70 or 80 years that chemicals have been widely used for destroying insects. Until recently, the principal insecticides used were pyrethrum, derris, nicotine, hydrocyanic acid, *p*-dichlorobenzene, and various organic thiocyanates, together with inorganic poisons such as arsenious oxide, arsenites, and lead salts. The use of inorganic poisons is to be deprecated because they are so dangerous to animal life.

Of these insect poisons, only the active principles of pyrethrum and derris, viz. the pyrethrins and rotenone respectively, affect insects in the smallest doses and are not dangerous to animals. Since pyrethrum and derris are expensive and the supply is limited, investigators have for some years been looking for easily synthesized substances to replace them. From 1934–39 the insecticidal properties of several thousand substances were investigated by Lean and others, using grain weevils, flies, locusts, mosquitos, and certain aphides as test organisms. Many substances poisonous to insects were found, but none so effective as the pyrethrins or rotenone. Most substances which kill insects also harm plants and animals.

In 1939 the method of investigating the problem was changed. A limited number of insect pests was selected and a search was made for the chemicals and methods best suited to fight them. Early in 1942 attention was particularly directed towards the turnip flea beetle. Several substances were tried, including heptachlorocyclohexane and octochlorocyclohexane. A sample of benzene hexachloride or 1,2,3,4,5,6-hexachlorocyclohexane ($C_6H_6Cl_6$) was also tried. For convenience this was named 666. Laboratory and small scale field trials of 666 in the summer of 1942 were most encouraging, although the toxicity varied somewhat from one sample to another. It was decided to use benzene hexachloride in place of derris in flea beetle powder for the spring and summer of 1943. The powder was standardized by biological tests. Some hundreds of tons were used, and the powder proved at least as effective as powders made with derris.

Meanwhile the cause of the inconsistent action of different samples was investigated, particular attention being paid to the possibilities that an impurity might be the active principle, or that the various isomeric forms of benzene hexachloride might vary in their activity.

Benzene hexachloride was first prepared by Michael Faraday, who made it by chlorinating bi-carburet of hydrogen (benzene) in sunlight. In 1833, Mitscherlich described the decomposition of benzene hexachloride to trichlorobenzene by means of bases. Péligot and Laurent settled its composition in 1836. Meunier then showed that it contained two isomers, the alpha isomer melting at 157° C and the beta at a much higher temperature. In 1912, van der Linden established the existence of four isomers.

In 1942, Burrage *et al.* prepared pure specimens of the alpha and beta isomers, and investigated their toxicity to insects. Neither proved very toxic, the beta form being hardly toxic at all. Early in 1943 they isolated the gamma isomer and found it to be more toxic to weevils than any substance which had ever been tested. The delta isomer was found to be only moderately toxic. It was thus shown that the toxicity of benzene hexachloride was due almost entirely to the gamma isomer, which was named 'gammexane.'

The four isomers can be obtained from crude 666 by making use of their different solubilities in various solvents such as benzene, chloroform, or methyl alcohol.

The melting points of these isomers are now known to be:

TABLE I

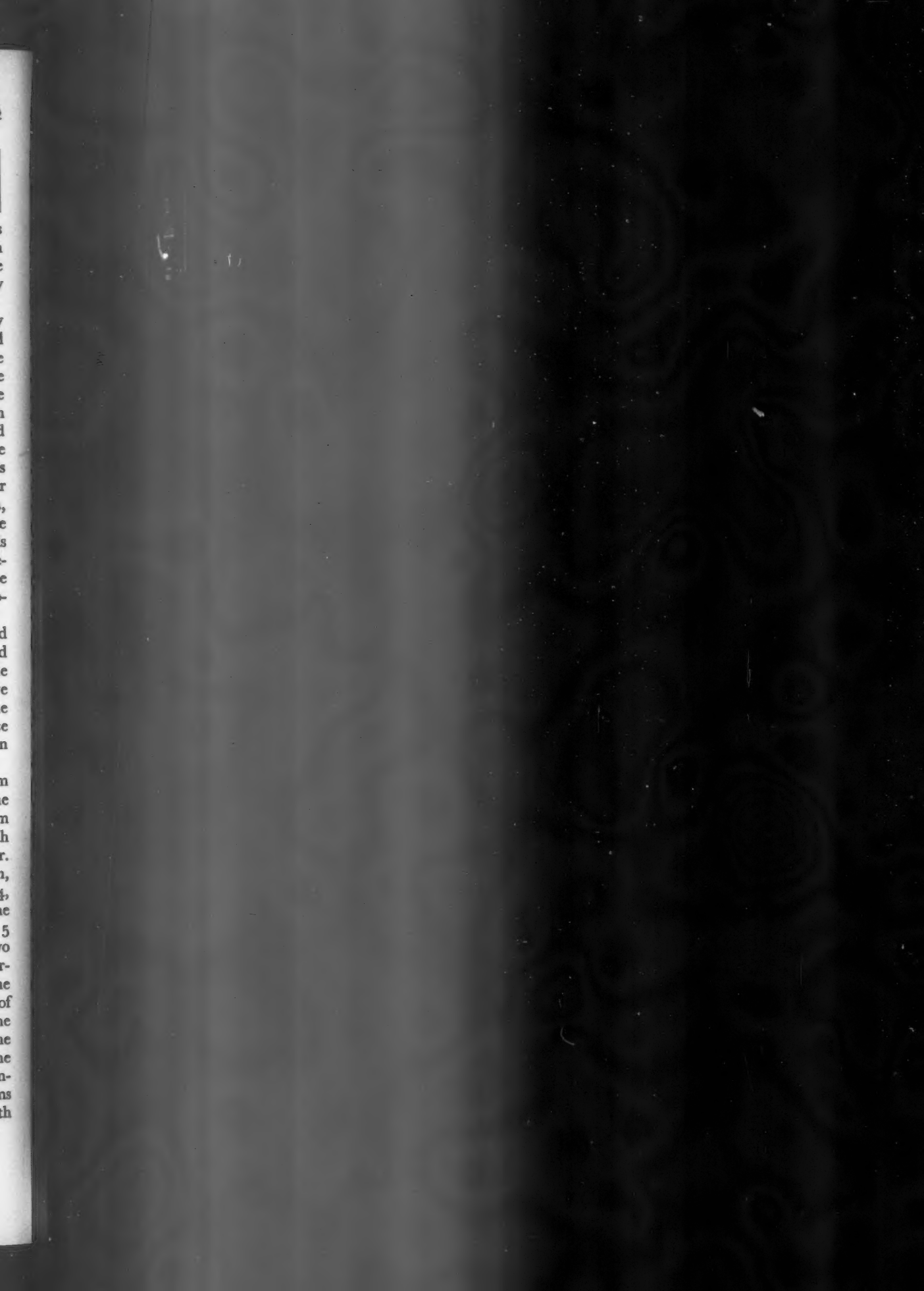
| | | | |
|---|---|---|---|
| Alpha .. | 157·5°–158° C | Gamma .. | 112·5° C |
| Beta .. | 309° C | Delta .. | 138°–139° C |

The atomic structure of the four known isomers can be deduced with the aid of atomic models in which the distances between the model atoms are proportional to those determined by X-ray analysis.

Figure 1 shows the six carbon atoms as they occur in the cyclohexane ring. It will be noticed that three of the carbon atoms are in one plane and the other three in another plane. If three hydrogen atoms are fixed on to the top of the three upper carbon atoms and three hydrogen atoms below the three lower carbon atoms, and if six chlorine atoms are then fixed in the outside ring, the atomic model shown in figure 2 is obtained. In these figures the upper and larger model is photographed directly by the camera, whilst the smaller model is the reflection of the underside of the upper model in a mirror. This atomic model is centro-symmetrical and is therefore the beta isomer, which crystallizes in the regular system and has been shown to be centro-symmetrical by X-ray analysis.

In figure 3 one of the hydrogen atoms attached to a carbon atom in the lower plane has changed places with the chlorine atom attached to the same carbon atom, so that in this isomer we have one chlorine atom in the lower plane and one hydrogen atom in the outside ring. The presence of the chlorine in the lower plane can be seen from the mirror image.

It is obvious from figure 3 that there is not room for another chlorine atom to replace one of the two remaining hydrogen atoms in the bottom layer, but a chlorine atom can change places with one of the three hydrogen atoms in the top layer. This can be either the back hydrogen atom, which is shown replaced by chlorine in figure 4, or one of the other two hydrogen atoms. The one on the right has been changed over in figure 5 and the one on the left in figure 6. These two forms are not quite identical, but are mirror-images of each other. They are likely to have the same melting point and to form together one of the known isomers. We believe that this is the alpha isomer, and that figure 4 represents the delta isomer. From a statistical treatment of the additive process of chlorination, Burrage concludes that the arrangement of chlorine atoms present in the alpha isomer, which includes both



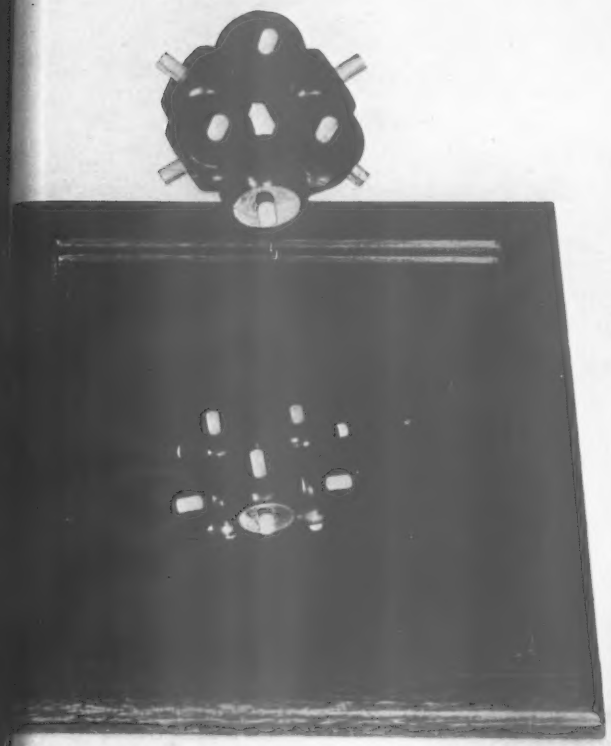


FIGURE 1

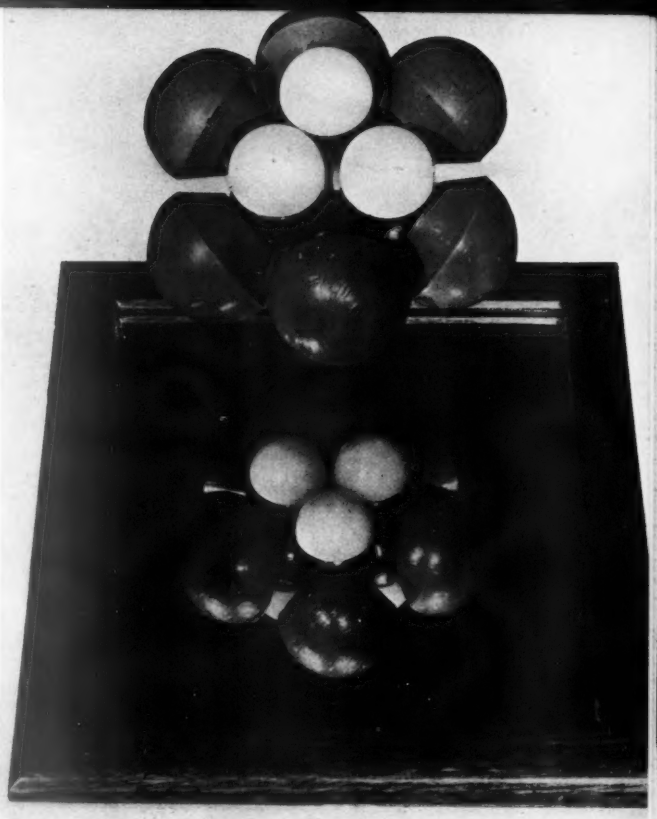


FIGURE 2

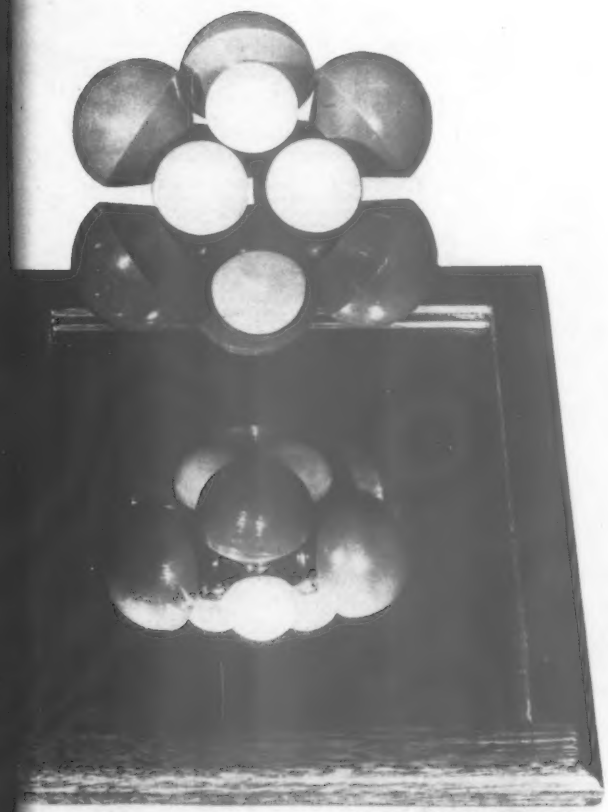


FIGURE 3

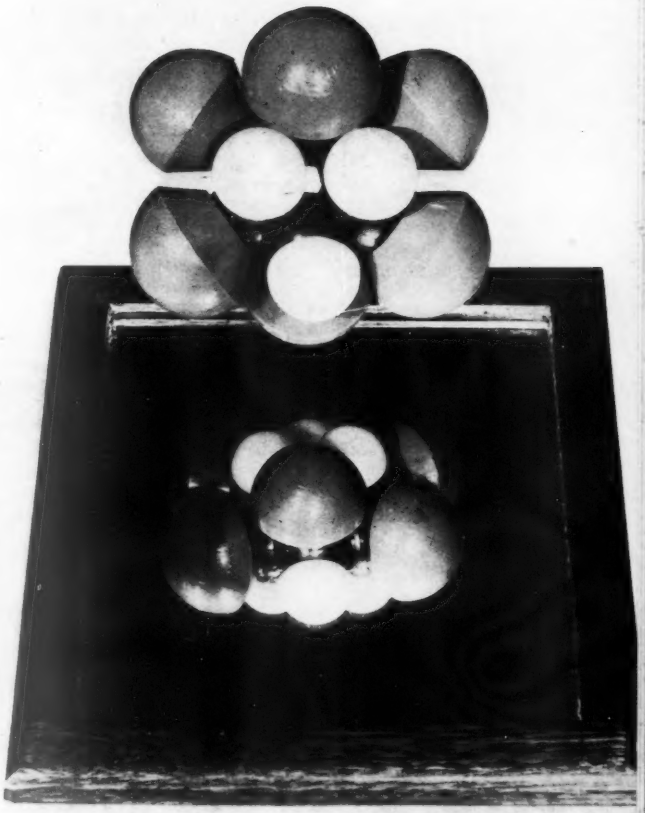


FIGURE 4

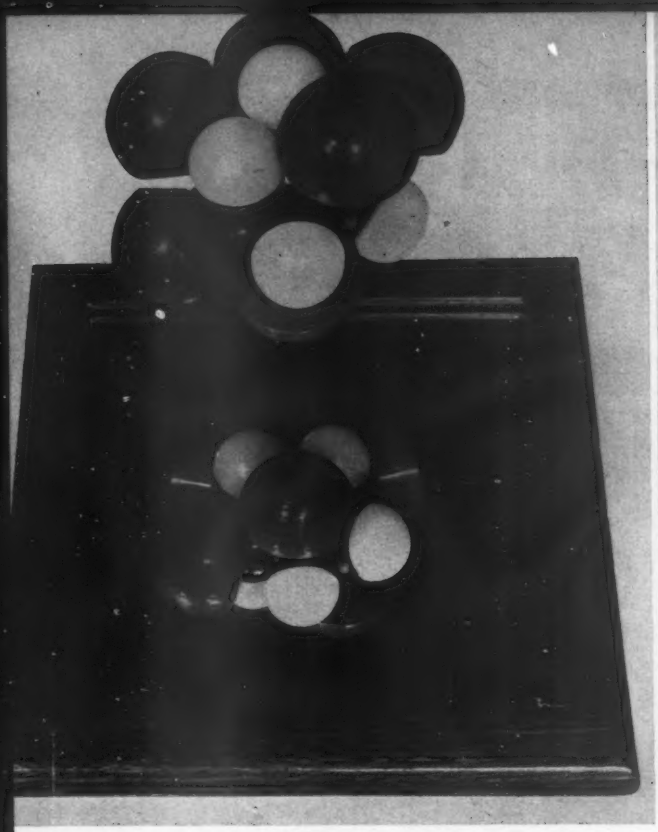


FIGURE 5

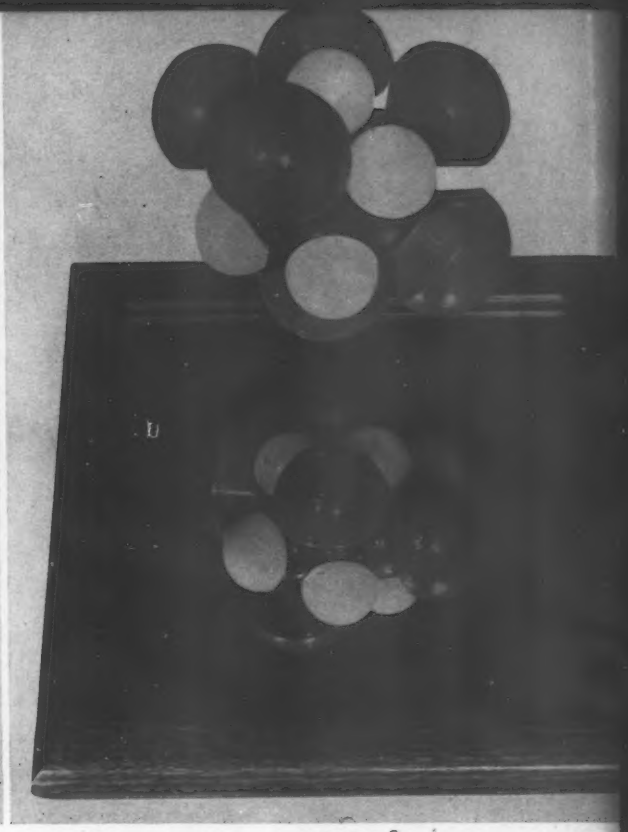


FIGURE 6

mirror-image forms, has the highest probability, whilst the arrangement of the chlorine atoms in the isomer which is centro-symmetrical has the lowest probability.

It has been found that in the chlorination product there is about 5 per cent. of the beta isomer and up to 70 per cent. of the alpha isomer. This suggests that the alpha isomer is the one with enantiomorphic forms. The exact definition of the gamma and delta isomers must await detailed X-ray examination, but it is suggested that the gamma structure is that given by figure 3.

The toxicity of the different isomers has been determined for many insects. The results against the grain weevil are given in table II. For purposes of comparison the corresponding figures are given for D.D.T. (dichloro-diphenyl-trichloroethane), another powerful new insecticide. For the house-fly similar results have been recorded.

The toxicity of various insecticides, including gammexane and D.D.T., towards larvae of the yellow fever mosquito is shown in table III.

Gammexane is particularly toxic to locusts, and the results of trials in North Africa suggest that by means of this substance locusts may be effectively controlled. The results of toxicity tests against locusts are shown in table IV.

Although gammexane is so highly toxic to insects, it is not very toxic to animals and it hardly affects the leaves of plants. The toxicity towards rats has been tested by H. Taylor in terms of the quantity per kilogram of body-weight necessary to kill 50 per cent. of the animals within seven days. In all cases the material was introduced directly into the stomach. Results are given in table V.

TABLE II

*Relative toxicity of the isomers of benzene hexachloride to the grain weevil* (Calandria granaria) *when applied as grain dust*

By H. H. S. Bovingdon

| Isomer | Relative amounts by weight required to kill 50 per cent. of the pests in 5 days |
|---|---|
| Alpha .. .. .. .. | 900 |
| Beta .. .. .. .. | Almost non-toxic |
| Gamma (gammexane) .. | 1 |
| Delta .. .. .. .. | 5,500 |
| D.D.T. .. .. .. | 15 |

TABLE III

*Toxicity of the various insecticides to the larvae of the yellow fever mosquito* (Aedes Aegypti)

By F. J. D. Thomas

| Insecticide | lb./acre | Percentage of larvae dead | | |
|---|---|---|---|---|
| | | After 1 day | After 2 days | After 3 days |
| Crude benzene hexachloride, 666 .. .. | 0·5 | 0 | 23 | 93 |
| | 0·06 | 0 | 0 | 20 |
| Gammexane .. .. | 0·5 | 0 | 97 | 100 |
| | 0·06 | 0 | 33 | 80 |
| Cuprous cyanide .. .. | 0·5 | 47 | 73 | 87 |
| | 0·06 | 30 | 40 | 65 |
| D.D.T. .. .. .. | 0·5 | 0 | 43 | 97 |
| | 0·06 | 0 | 23 | 47 |
| Carrier dust only .. .. | 10·0 | 0 | 0 | 13 |

TABLE IV

*Laboratory poison bait tests against the African migratory locust* (Locusta migratoria migratorioides)

By M. D. Price

| Insecticide | Concentration per cent. in bait | Percentage dead after 2 days |
|---|---|---|
| Crude benzene hexachloride, 666 .. .. | 0·02 | 62 |
| | 0·05 | 96 |
| Sodium arsenite .. .. | 4·0 | 66 |
| D.D.T. .. .. .. | 0·2 | 57 |

TABLE V

| | |
|---|---|
| Alpha isomer .. .. .. | 1·7 gm. per kg. |
| Beta isomer .. .. .. | No animals were killed |
| Gamma isomer (gammexane) .. | 0·19 gm. per kg. |
| Delta isomer .. .. .. | 1·00 gm. per kg. |
| The mixture of isomers .. .. | 1·25 gm. per kg. |

The chronic toxicity has been investigated by feeding small daily doses to rats for several weeks. Results indicate that small quantities can be got rid of without any ill effects being suffered even after two months of treatment. The effect on the skin has been tested by painting the skins and the tails of the rats twice daily with an emulsion containing 5 per cent. of the mixed isomers. No ill effects were observed even after a fortnight. E. L. Taylor has shown that gammexane is toxic to the parasite of notoedric mange in rats, in concentrations that do not affect the host.

There appears to be little or no danger to animals or men from the use of 666 or gammexane, but with all new chemical materials the effect upon the skin must be carefully watched, since it is difficult to deduce the effect in man from animal experiments.

It is remarkable that gammexane, the gamma isomer, should be perhaps the most powerful insecticide at present known. Its mode of action is not fully clear, but the following facts may be indicative. Inositol has a structure similar to benzene hexachloride except that the chlorine atoms are replaced by hydroxyl groups. Inositol is thus 1,2,3,4,5,6-hexahydroxycyclohexane. It has been shown that the naturally occurring inositol isomer, *meso*-inositol, has a structure similar to that proposed for gammexane (figure 3). *Meso*-inositol occurs as a material constituent in practically all plant and animal cells, and is associated in its action with the vitamin B complex. It has been suggested that because of the similarity of its structure gammexane takes the place of *meso*-inositol in an essential cell action. The normal reaction is thus prevented. This is in accordance with the theory of the mode of action of sulphonamide drugs put forward by Fildes and Woods. They suggested that the toxicity of sulphonamides towards bacteria is due to the acceptance in some cell reaction of a molecule of sulphonamide in place of the structurally similar *p*-aminobenzoic acid. This suggestion is supported by the fact that the activity of sulphonamides is neutralized by excess of *p*-aminobenzoic acid. It has not yet been possible to determine whether an excess of *meso*-inositol will minimize the effect of gammexane on insects. If the above theory of the action of gammexane is correct it is strange that the substance is not also very toxic to animals and plants. When we know more of the chemical physiology of insects it may be possible to find an explanation.

# Recent applications of chemical spectroscopy

H. W. THOMPSON

Developments in chemical spectroscopy have led to its use in structural diagnosis, in qualitative and quantitative analysis, and in the derivation of other important chemical data. Earlier work mainly concerned ultra-violet spectra, but marked advances have recently resulted from the study of the infra-red spectra of larger molecules such as plastics and synthetic rubbers, and the method now ranks high among physico-chemical techniques.

According to the quantum theory, a molecule emits or absorbs electromagnetic radiations by passing from one energy level to another, according to the equation $E = h\nu$, where E is the difference in energy between the two levels and $\nu$ is the frequency of the radiation emitted or absorbed. The determination of these energy levels from spectroscopic measurements has considerably increased our knowledge of molecular structure and of interatomic and intermolecular forces, and has augmented our understanding of thermal and photochemical reactions.

When energy is absorbed by an atom, it is used to raise an electron from a lower to a higher level. In the case of molecules, with which chemistry is primarily concerned, it may be used for two other purposes as well, namely to produce vibration of the nuclear skeleton or to cause rotation of the molecule as a whole. The quanta of rotational energy are very small, and give rise to absorption in the far infra-red at wave-lengths of about 1 cm. When vibrational quanta are taken up, the region of absorption moves to the near infra-red between wave-lengths of about 1 μ and 100 μ ($10^{-4}$ to $10^{-2}$ cm.). Absorption of electronic quanta gives spectra in the visible or ultra-violet region of still shorter wave-lengths ($10^{-4}$ to $2 \times 10^{-5}$ cm.).

Little is yet known about the spectra of molecules in the far infra-red region around 1 cm. wave-length, although the use of ultra-short radio waves now promises to open up a vast new field for exploration. This may lead not only to the correlation of molecular rotational energy levels with molecular structure, but also in the case of liquids and solids to fundamental knowledge about the dissipation of energy—power loss—caused by the anomalous dispersion of dielectrics. In this connection the function of molecular dipoles is important, and the formulation of a more exact mathematical theory of these phenomena may be expected to follow when further experimental results are available.

Data obtained from the electronic spectra of diatomic molecules are now extensive. Associated with the change in electronic energy, there is a series of changes of vibrational energy, and with each of the latter a simultaneous alteration in rotational energy may occur. These rotational energy changes accompanying a vibrational energy change give rise to a group of spectral frequencies called a band, and the series of bands associated with the particular electronic transition forms a band system. The rotational structure within a band is determined by two factors: the moments of inertia of the molecule in the two states between which the transition occurs, and the particular nature of the electronic states involved. Analysis of the rotational structure therefore leads to values for the moment of inertia, and hence to the bond-length; and data are also obtained about the relative stability of different types of electronic structure which are valuable in constructing theories of valency.

From the arrangement of the vibration bands in a system, we are often able to determine the heat of dissociation of the molecule and the fundamental vibration frequency, and to derive other results of wide applicability, such as the function expressing the way in which the potential energy of the molecule varies during a vibration. If the diatomic molecule is regarded as a pair of mass-points vibrating with simple harmonic motion, we can use the fundamental frequency to calculate the force-constant of the bond for stretching, and this quantity has been useful in comparing single, multiple, and hybrid links. Empirical equations are also now available which relate the force-constant of a bond between a

given pair of atoms to its length, and these can be used to estimate the bond-length from the force-constant when for some reason the former cannot be determined directly. Finally, it is now possible, using the measured vibration frequency and moment of inertia, to calculate with high accuracy the thermodynamic properties of a molecule, such as free energy, entropy, and specific heat. In this way precise values have also been obtained for equilibrium constants of many reactions which cannot otherwise be determined.

By contrast with what happens with a diatomic molecule, the absorption of electronic energy by a polyatomic molecule often causes it to dissociate. With such molecules, therefore, emission spectra are rarely observed, and the visible or ultra-violet absorption spectra usually consist of broad regions of continuous absorption. In some of the few cases in which bands showing rotational structure have been found, moments of inertia and other structural data have been deduced; and certain spectra showing an incompletely resolved banded structure have been correlated with the processes involved in photochemical change. As a rule, however, the spectra of these larger molecules can be expressed only as curves, showing how the molecular extinction coefficient varies with wave-length. For analytical purposes these spectral curves have been very valuable, since they can be used to estimate, both qualitatively and quantitatively, many complex organic compounds of biological interest, such as hormones, vitamins, plant pigments, porphyrins, and their derivatives. Moreover, it has been found that certain atomic groupings have chromophoric character, and absorb strongly at specific wave-lengths; and other structural differences, such as that between *ortho*-, *meta*-, and *para*-derivatives, also lead to characteristic displacements. The results make it possible to determine in many complex organic products whether a particular group is present, or to decide between possible alternative structures.

More recently, the emphasis has tended to pass to the vibration-rotation spectra in the near infra-red. Most of this region can be studied with prism spectrometers in which surface mirrors replace lenses, and the prism and cell are made of quartz, rock-salt, fluorite, or potassium halides; the radiation is detected by means of thermo-electric devices. Technical improvements have made it possible to replace the earlier spectrometers by speedier automatically recording instruments, one of which is shown in figure 2. By comparison of the radiation transmitted through the substance with that transmitted through a blank cell or air, curves are obtained showing the percentage transmission at different wave-lengths. If the highest resolving power is required, grating spectrometers have to be used.

Whereas a diatomic molecule has only one mode of vibration, a polyatomic molecule has many, and although this renders the infra-red spectrum more complicated, it makes it more interesting. An assemblage of $n$ free atoms will have $3n$ translational degrees of freedom. When the atoms are joined together in a molecule, 3 degrees of freedom will be taken up by translational motion, and since the molecule will also, in general, be able to rotate about each of three mutually perpendicular axes, there will remain $(3n - 6)$ degrees of freedom for the remaining internal motions. These are the so-called 'normal' or 'proper' modes of vibration. Any arbitrary vibrational motion of the system will be derivable by a coupling together of two or more of these normal modes with suitable phase differences. With linear molecules such as HCN or $C_2H_2$, since there are only two effective rotational degrees of freedom, there will be $(3n - 5)$ normal modes, and for some molecules in which an internal molecular rotation occurs as well as the three overall molecular rotations, there will be $(3n - 7)$ vibrations.

With some simple symmetrical molecules, it is possible to specify the geometrical form of these oscillations and to classify them into various types. Thus, in figure 1 the vibrations of carbon dioxide (A) and acetylene (C) are either valency vibrations, in which the motion occurs along the valency bonds, or deformational modes, in which the motions occur in directions perpendicular to these bonds. The vibrations of the isosceles triangular model such as $H_2O$ are also either essentially along the bonds ($B_1$ and $B_2$) or essentially at right-angles to them ($B_3$). In some cases, too, vibrations can be visualized as 'rocking,' 'tilting,' 'bending,' or 'twisting' modes, shown in the figure for a molecule such as that of ethylene.

Molecular vibrations are also often distinguishable by the character of their symmetry and by the way in which the electric moment changes during the motion. Now we might expect, *a priori*, that when a molecule is irradiated with a beam of infra-red radiation containing all frequencies, it will absorb frequencies corresponding to every normal mode. This does not usually occur. Radiation is absorbed only when the vibration is accompanied by a changing electric moment, and the intensity

of absorption depends on the magnitude of this change. It follows that homonuclear molecules such as those of nitrogen will not absorb in the infra-red, and the same applies to vibrations such as A1 and C1 in figure 1. It also follows that the different vibrations actually observed in a given case will be absorbed with varying intensity. As regards those vibrations which involve a changing electric moment and are absorbed, the change in moment is in some cases parallel to an axis or plane of symmetry and in others perpendicular to it; but such a simplification is possible only when there is an axis of symmetry, and in the more usual case of asymmetrical molecules the vibrations are hybrid in character.

A few small molecules, volatile enough to be studied in the vapour state, have moments of inertia which are still low enough to make possible the resolution of the rotational structure of their vibration bands. The arrangement of these rotation lines varies according to the direction, with respect to the axis of symmetry, in which the electric moment changes in the vibration involved, but by a combination of measurements on several bands it is often possible to determine the three principal moments of inertia. It may then be possible to calculate the bond-lengths and angles, but it must be remembered that in most cases the number of unknown parameters (bond-lengths and angles) exceeds three, the maximum number of unique moments of inertia; and in such cases the molecular structure cannot be completely determined unless certain of the parameters are assumed. In some cases, deuterium has been used to resolve ambiguities. Thus, hydrogen cyanide, HCN, has only one unique moment of inertia, but there are two bond-lengths. Measurement of the moment of inertia for DCN provides a second moment of inertia for the same two bond-lengths, and thus two equations from which the bond-lengths can be determined with high accuracy.

Many data of this kind have been obtained for simple molecules, such as those of the methyl halides and lower hydrocarbons, and for the pyramidal molecules of ammonia. As the molecules increase in size, the moments of inertia become so large as to make the rotational structure unresolved, but the 'envelope' or 'contour' of this rotational structure can still sometimes be used to derive the moments of inertia. Also, this contour, or an incompletely resolved rotational structure, often tells us the direction of change of electric moment in a particular type of vibration, and in this way important qualitative inferences can be drawn about the molecular configuration when several alternative stereochemical configurations are possible.

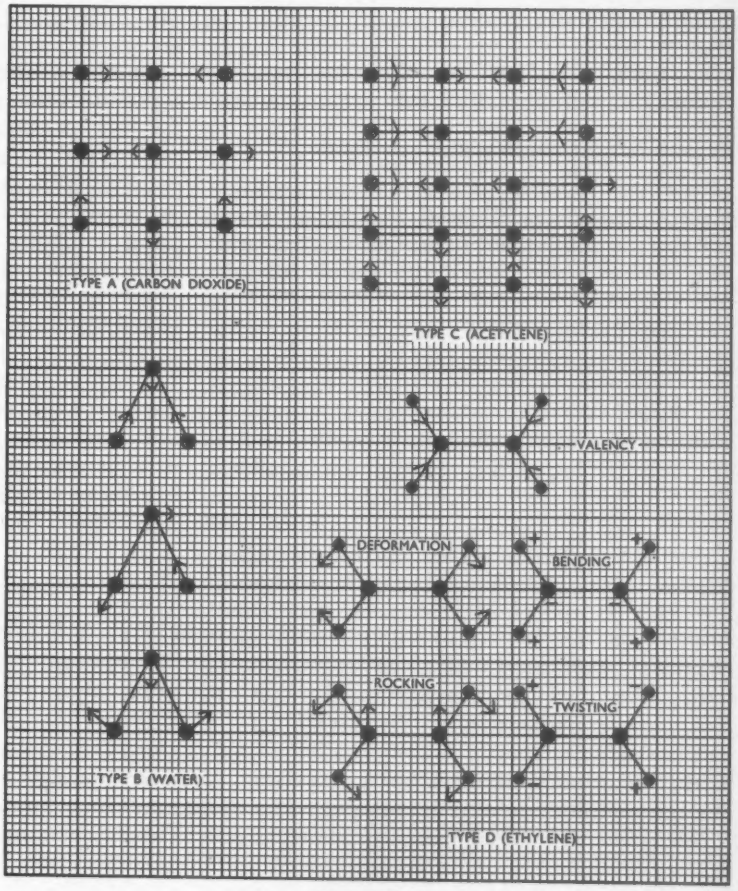



FIGURE 1

With larger molecules—which are in fact the majority, and which must be examined in the liquid or solid state or in solution—it is possible to determine the vibrational frequencies only, and the results can be used in two ways. If *all*

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the vibration frequencies can be determined and assigned to particular normal modes, their values can be used in calculating other more valuable properties such as the force-constants for stretching of links and bending of angles and the thermodynamic properties mentioned earlier. With most molecules this remains an ideal not easily achieved. As explained already, some vibrations may not be observed in the absorption spectrum. These may, however, be found in the Raman spectrum, where the appearance of a vibration frequency is governed by changes of polarizability during the vibration rather than by change in electric moment; or sometimes the frequencies are obtained from fluorescence data.

Numerous attempts have been made to calculate force-constants, but apart from considerable mathematical difficulties in such co-ordinate treatments, it is now clear that the choice of a slightly unsatisfactory potential energy function for the vibrations may place all the results in doubt, and satisfactory means of testing their reliability are rarely available. Comparison of calculated and measured thermodynamic properties has been more fruitful. Thus, the calculated and measured values of the specific heat or entropy of many molecules having a rigid framework agree closely. With some other molecules, discrepancies have been correlated with the occurrence of more or less restricted internal rotation of groups about single bonds. Estimates of the potential energy barriers resisting such internal torsión have now been made in sufficient cases for us to begin to formulate reasons for the restriction of free rotation about a variety of single bonds.

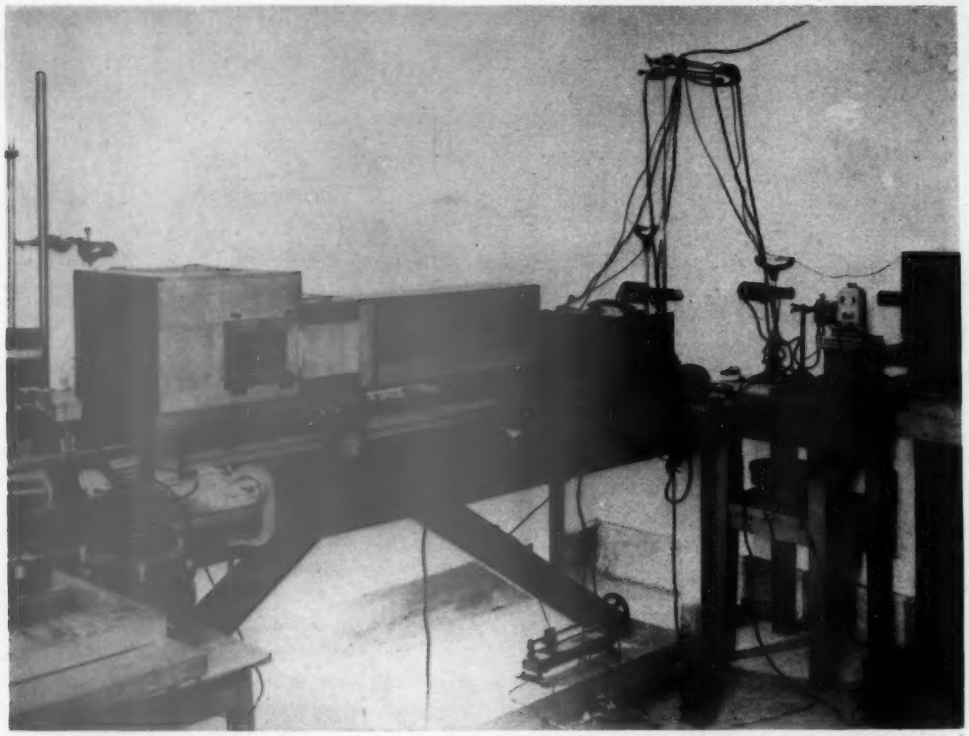


FIGURE 2

The usefulness of infra-red absorption data is by no means confined, however, to the above-mentioned ideal of determining and assigning correctly all the vibration frequencies, and its power for qualitative and quantitative analysis and structural diagnosis is now becoming widely appreciated. Thus, experience has shown that certain groups (for example C=C, C=O, OH) have vibration frequencies which remain almost unaffected when the group is present in different molecules. Although in reality the entire molecule takes part in any oscillation, these groups have frequencies of vibration which remain sufficiently nearly constant to make them characteristic. Thus if any substance known to contain the O–H group fails to

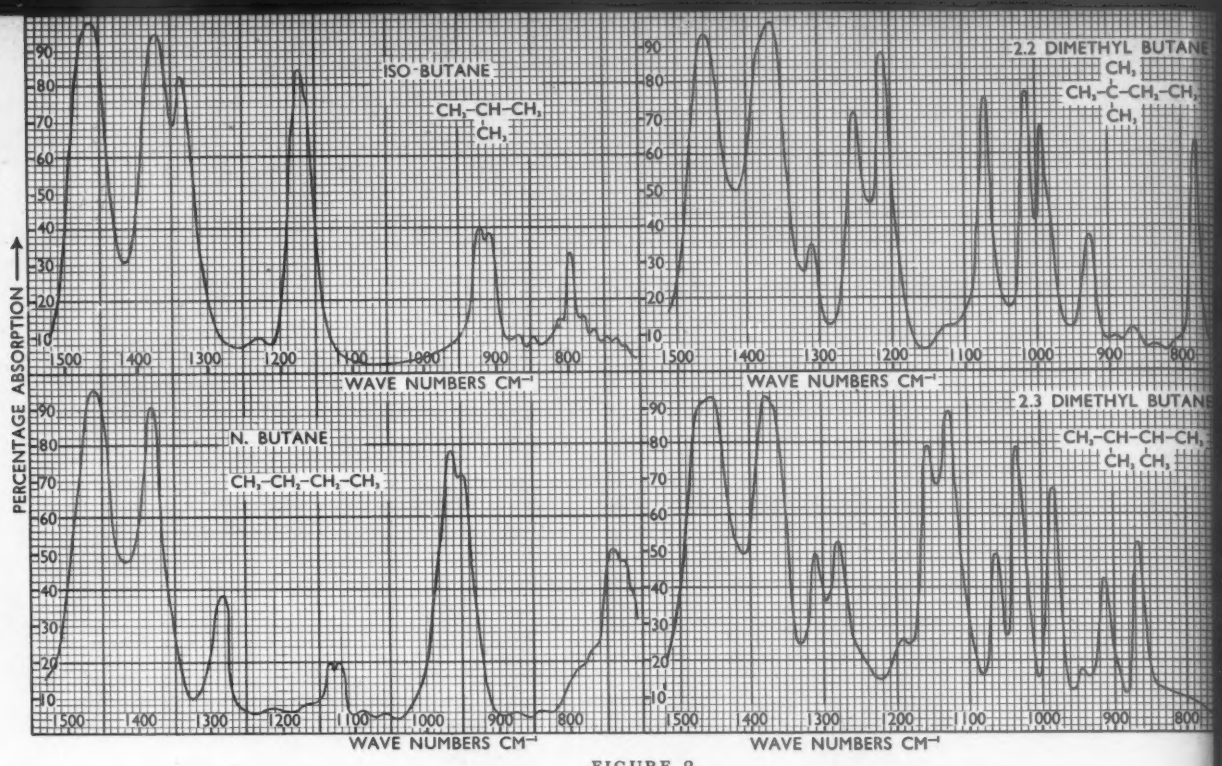



FIGURE 3

show the characteristic infra-red absorption band, we can infer that this group has been influenced in some way. A study of hydroxylic compounds in this connexion (e.g. carboxylic acids, alcohols, phenols) has now revealed the existence of hydrogen bridges of the type –O–H– – –O– in many of these molecules.

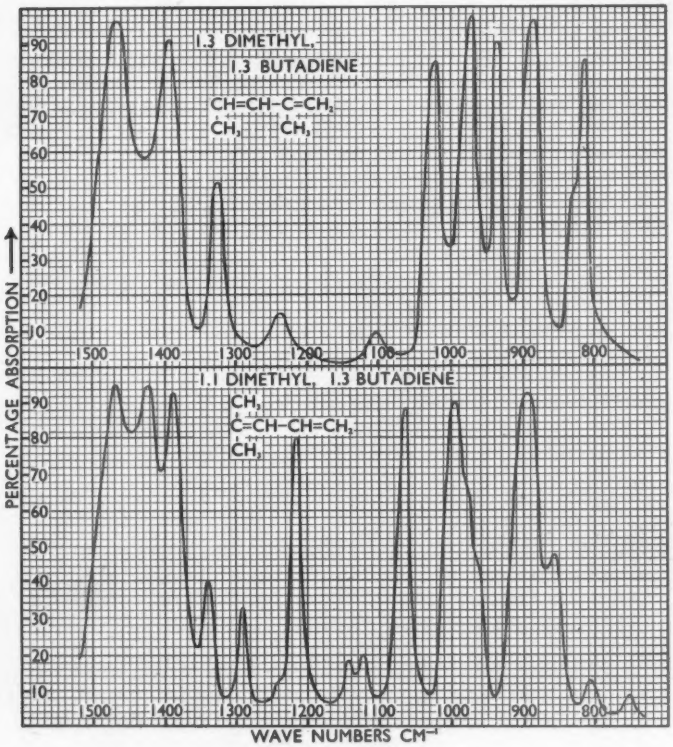



FIGURE 4

The individuality of the vibration spectrum of a large molecule has other even more important consequences. In principle, if two molecules have a different nuclear skeleton, they cannot have a completely identical set of vibration frequencies, and this will be true for molecules as closely similar as a pair of *cis-trans* isomers. Figure 3 shows the spectra of (*a*) normal and *iso*-butane, and (*b*) two isomeric hexanes. In each case there are such characteristic differences that estimation of each isomer in a mixture of both is directly possible. The importance of this for the analysis of mixtures of closely boiling isomers is obviously considerable. Figure 4 shows a similar pair of isomeric dimethyl butadienes, the analysis for each of which in a mixture would be difficult, if not impossible, by normal chemical methods. Each isomer shows characteristic bands at different wave-lengths, and an analysis could be carried out in a few minutes with about 1 c.c. of material. Other similar analyses have been worked out for mixtures of cresols

TANE
CH,
800
UTANE
-CH,
800

FIGURE 5

and of xylenols, and for the determination of the new insecticide gammexane in a complex mixture of its stereo-isomers. Analyses of this kind are altogether more satisfactory than could be made by using the Raman effect, and in many cases, too, they are also preferable to those using ultra-violet absorption, since the latter too often consists of continuous absorption regions, whereas sharp characteristic bands are observed in the infra-red. This new analytical method promises to have wide applicability in organic chemistry.

Another field in which the infra-red absorption has already found valuable application is that of polymeric chemistry. It will be clear from the remarks made above that a polymer will be expected to show a different spectrum from its parent monomer. Figure 5 shows the spectra of polyvinyl chloride and poly*iso*butylene, together with those of the monomers. We have here, therefore, a most convenient method for the measurement of rates of polymerization and for process control. More important, however, is the fact that the measurements enable us simultaneously to follow the mechanism of such polymerizations, and to determine in some measure the structures of the plastics, rubbers, or polymers which may be formed. Thus, there is already evidence that just as individual linkages such as C=O, O–H, may give rise to one vibration frequency unchanged in different compounds, so also small parts of a nuclear skeleton may have an essentially constant set of vibration frequencies regardless of the nature of the remainder of the molecule. Results with simple olefines have shown that it is possible to identify different types of substituted ethylene by means of characteristic absorption bands, and this enables us to determine the proportions of 1,2 or 1,4 addition of conjugated dienes such as 1,3 butadiene or isoprene. When the former polymerizes, 1,4 addition will lead to the structure

$$-CH_2-CH=CH-CH_2-CH_2-CH=CH-CH_2-$$

and 1,2 addition to

$$-CH_2-\underset{\displaystyle CH \\ \displaystyle \| \\ \displaystyle CH_2}{CH}-CH_2-\underset{\displaystyle CH \\ \displaystyle \| \\ \displaystyle CH_2}{CH}-$$

and the proportions of each are at once revealed by the absorption spectrum. This rapid method has made it possible to examine how the chemical nature of the different molecules forming copolymers, such as butadiene with styrene or acrylonitrile, or the special conditions under which the reactions are carried out, affect the structure of the product. This is of great importance, since the physical properties of rubber and plastics may be fundamentally affected by the degree of branching of long chains, as also by other factors such as cyclization.

# Book reviews

### NEW MATERIALS

Materials of To-morrow, *by Paul I. Smith. Pp.* 140, *with* 18 *plates. Hutchinson's Scientific and Technical Publications, London.* 1945. 12*s.* 6*d. net.*

Here are facts in plenty, about the production, properties, applications and economics of plastics, synthetic rubbers, the new woods and steels, light metals, cements, structural glass, new textiles, modern ceramics, synthetic adhesives, and new drugs. It is clear that World War No. 2 has carried us well over the threshold of a new material and industrial world, concerned increasingly with research in pure and industrial science. The author emphasizes that technological supremacy is a prime factor of national security, and advocates the provision in Britain of vastly improved technological facilities in education. He tells us that one American company alone spends more money on research than all the British concerns combined. British research, he says, should be financed from revenue, as in the U.S.A., instead of being a charge on capital. He calls for rigid economy in the use of raw coal, and 'the immediate cessation of the export of this, our chief industrial capital.' He urges too, the construction of oil refineries at our large ports. He looks to Canada, with its minerals, water power, and manufacturing potentialities, as the future commercial centre of the British Commonwealth, and considers as inevitable the migration to Canada of a large proportion of Britain's skilled workers.

Our politicians, in particular, might use this informative and stimulating work to broaden their views on some essential matters. The book has been compressed within the unattractive framework of 'authorized economy standards': how many of us—like the boy companion of Ancient Pistol, who set a pot of ale above all else—would willingly sacrifice some of the materials of to-morrow for our yesterday's supply of good, honest, old-fashioned paper!

JOHN READ

### TREATISE ON THE ALGAE

The Structure and Reproduction of the Algae, *by F. E. Fritsch. Vol. II. Pp.* 939, *with* 1 *plate,* 2 *maps and* 336 *text illustrations. University Press, Cambridge.* 1945. 50*s. net.*

The appearance of the second volume of Fritsch's treatise on the algae has been eagerly awaited. In a foreword, the author discusses the conditions of life of the seaweeds in the littoral and sublittoral coastal regions of the world, and gives a brief account of their ecology and geographical distribution. The main part of the volume deals exhaustively with the morphology of the Phaeophyceae, Rhodophyceae and Myxophyceae. Recent classifications have been adopted in the groups, and physiological and ecological material has been included where it is relevant to a more complete understanding of the general thesis. The author summarizes and discusses most of the relevant literature published up to the middle of 1943, as far as it has been available. One especially valuable feature is the extensive list of references which is appended to each section. Profuse illustrations have been included from numerous sources, but some of these, especially habit drawings of plants, have unfortunately suffered in reduction. The volume completes a work which will doubtless remain a classic, and English-speaking scientists are especially fortunate in that it is written in their own language. Its production under present conditions is an achievement which merits warmest congratulations to both author and publisher.

LILY NEWTON

### POPULAR SCIENCE BROADCASTS

Science at Your Service, *by Julian Huxley, Sir Lawrence Bragg, E. C. Bullard, John Read, Sir Edward Appleton and others. Pp.* 102. *George Allen & Unwin Limited, London.* 1945. 6*s.* net.

The title adequately sets out the purpose of the book, though one can imagine the phrase repeated with ironic emphasis by a sufferer from the ravages entailed by war. Still, science has immense potentialities for increasing the material amenities of life, and for bringing nearer that reign of plenty for all the nations which has hitherto proved to be an elusive and indeed unattainable ideal. This admirable series of broadcasts deals with twelve topics—Science and the House, Building, Plastics, Clothing and Fabrics, Explosives, Sounding the Earth's Crust, Weather, The Housewife and the Fisheries, Saving Life at Sea, Ship Design, Tunnel Builders, and Science in National Life.

All the subjects discussed are important, and they form but a small proportion of similar topics suited for broadcast talks such as will, we trust, materialize in the near future. The authors have, each in his own way, amply demonstrated two points—that science has an increasingly important part to play in our personal and social life, and that, despite the amazingly complicated technique which characterizes the growth of science in our generation, it is possible, by a skilful use of analogy and illustration, to convey to the lay listener some adequate notions, not only of the results, but also of the method and spirit of scientific research. The book may be warmly and unreservedly recommended.

ALLAN FERGUSON

### THE MEANING OF TIME

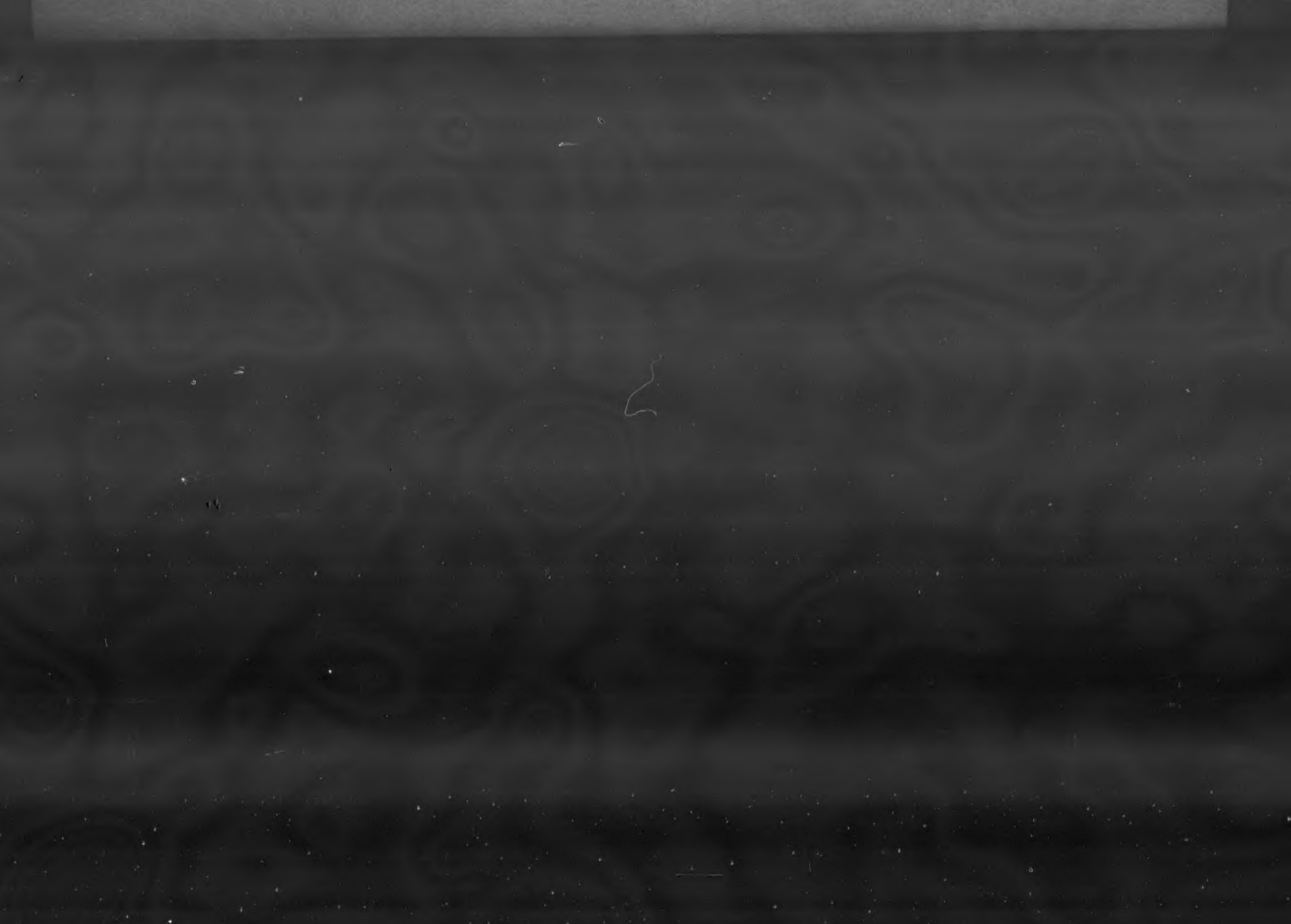
Time, Knowledge, and the Nebulae, *by Martin Johnson. Pp.* 189. *Faber & Faber Limited, London.* 1945. 12*s.* 6*d.* net.

This is a discussion of the meaning of Time, with particular reference to Professor E. A. Milne's Kinematical Relativity. As a primitive idea the author takes 'signal velocity,' asserting it to be a 'fundamental requirement' that 'a velocity of signal propagation shall be regarded as constant in any coherent system of knowledge' (p. 51).

Now it is possible to conceive a universe with a Euclidean metric and an aether (to use nineteenth-century language) whose dielectric constant varies slowly from place to place, so that the velocity of light differs as we pass from one region of the world to another. If our universe had been of this kind, there would have been nothing to prevent physicists, using nineteenth-century methods, from finding out as much about it as the nineteenth-century physicists found out about our actual universe. This seems to disprove Dr Johnson's assertion that constancy of signal velocity is a necessity of science.

The proof offered for the well-known equations of special relativity is defective for other reasons besides this: and the book as a whole, which gives evidence of the author's wide reading and breadth of interests, suggests that his critical faculty is not as well-developed as his gift of sympathetic appreciation.

E. T. WHITTAKER



# Notes on contributors

Sir HAROLD SPENCER JONES,
*M.A., Sc.D., B.Sc., F.R.A.S., F.R.S.*,

Has held the position of Astronomer Royal since the year 1933. He was born in London in 1890 and was educated at Latymer Upper School, Hammersmith, and Jesus College, Cambridge. From 1913–23 he was Chief Assistant at the Royal Observatory at Greenwich, and from 1923–33 held the post of His Majesty's Astronomer at the Cape of Good Hope. He was knighted in 1943, and in the same year was awarded the Royal Medal of the Royal Society and the Gold Medal of the Royal Astronomical Society. He is a past president of the latter Society and of the British Astronomical Association, and was vice-president of the International Astronomical Union from 1935 to 1938. President of the British Horological Institute, he is also a Foreign Associate of the National Academy of Sciences (U.S.A.), and an Honorary Member of many Dominion and foreign astronomical societies.

ALEXANDER WOOD,
*M.A.* (*Cantab.*), *D.Sc.* (*Glasgow*),

Was born in 1879, and was educated at Hamilton Crescent Public School, Partick, and the Universities of Glasgow and Cambridge. He was elected a Fellow of Emmanuel College, Cambridge, in 1907, and since 1920 has been University Lecturer in Experimental Physics. His physical research has been devoted mainly to the study of sound, and on this subject he has written many scientific papers and several books. An interesting feature of his work is a study of the physical principles of music. His books include *The Physical Basis of Music*, *Sound Waves and their Uses*, and *A Text-book of Acoustics*. He takes an active interest in politics and local government, and was chairman of the Cambridge University Labour Party in 1927. His chief recreation is sailing.

G. S. CARTER,
*M.A.* (*Cantab.*), *Ph.D.*,

Was born in 1893. His academic career at Gonville and Caius College, Cambridge, was interrupted by the war of 1914–18, in which he served first with the Leicestershire Regiment and later with the Sound-Ranging Section of the Royal Engineers. He returned to Cambridge in 1919 to resume his work there. In 1924 he was appointed Lecturer in Zoology at the University of Glasgow. In 1930 he was elected a Fellow of Corpus Christi College, Cambridge, where he has since remained. Dr Carter has conducted expeditions to the Paraguayan Chaco and British Guiana with the object of studying the conditions of life in tropical fresh waters, especially those concerning adaptations of the fish fauna. Since 1933 his research has been concerned chiefly with comparative endocrinology, particularly of thyroid substances. He has published many papers on his work, and also a book *General Zoology of the Invertebrates* (1940).

ALEXANDER HADDOW,
*M.D., D.Sc., Ph.D.*

Born in 1907 at Leven in the 'Kingdom' of Fife. Educated at Broxburn High School and the University of Edinburgh, where he graduated in 1929 and later became Lecturer in Bacteriology (1931–36). During this time published a number of papers on special aspects of the experimental pathology of growth (mainly problems of immunity and the principles governing the transplantation of tissues) and on the phenomena of 'dissociation' in bacteria. In 1935 discovered a growth-inhibitory property characteristic of carcinogenic compounds and has spent some years—since 1937 with Kennaway at the Chester Beatty Research Institute of the Royal Cancer Hospital—in developing this subject and relating it to the mechanism of action of tumour-producing agents generally.

K. M. RUDALL,
*M.Sc., Ph.D.*,

Was born in 1910, and was educated at Auckland Grammar School and at the University of New Zealand. Some of his early research work (with F. W. Dry) dealt with problems of mammalian hair growth; but since 1935 he has turned to an investigation of a variety of animal tissues by means of X-ray analysis, aiming at an understanding of the function and structural interrelationships of biological macromolecules. He has also developed the technique of electron microscopy as applied to fibrous proteins and tissues. Author of many original articles in scientific journals, he finds relaxation from science in playing hockey in the winter and cricket whenever possible.

R. E. SLADE,
*M.C., D.Sc.* (*Vict.*), *Hon. D.Sc.* (*Dunelm.*), *F.R.I.C.*,

Was born in Cheshire in 1886, and was educated at the Victoria University of Manchester. He was afterwards lecturer in physical chemistry at the University of Liverpool and later at University College, London. On the outbreak of the war of 1914–18 he joined the Special Brigade of the Royal Engineers, reaching the rank of captain and being awarded the Military Cross. After the war he became the first director of the Photographic Research Association; this was the first industrial research association to be set up after the formation of the Department of Scientific and Industrial Research. In 1920 he joined Messrs Brunner Mond, one of the original constituents of Imperial Chemical Industries, to plan the development of the ammonia plant at Billingham. He eventually became managing director at Billingham, which is the largest chemical works in the British Empire and the second largest in the world. Since 1935 he has taken charge of research for Imperial Chemical Industries. Recently, he has become known to the world as one of the 'atomic bomb' team of scientists. Energetic in all things, his hobby is farming.

H. W. THOMPSON,
*M.A., B.Sc.* (*Oxon.*), *Phil.D.* (*Berlin*),

Born in 1908, he was educated at King Edward VII School, Sheffield, and Trinity College, Oxford, where he had a distinguished academic career. After a short period of research in Germany he returned to Oxford to become a Fellow of St. John's College; Lecturer in Chemistry and University Demonstrator, Dr Thompson is a physical chemist whose main interest is in spectroscopy, particularly of the infra-red region of the spectrum. In this field he has published a number of valuable papers; he is also the author of a text-book on spectroscopy. During the war he was engaged on research for the Ministry of Supply and the Ministry of Aircraft Production.

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